

GRASSLAND BIRD RESPONSE TO LANDSCAPE-LEVEL AND SITE-SPECIFIC
VARIABLES IN THE LITTLE MISSOURI NATIONAL GRASSLAND

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The Supervisory Committee certifies that this *disquisition* complies with North Dakota
State University's regulations and meets the accepted standards for the degree of

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ABSTRACT

Trend analysis from the North American Breeding Bird Survey indicates that the Sprague's pipit (*Anthus spragueii*) and Baird's sparrow (*Ammodramus bairdii*) populations have experienced severe annual declines of -3.5% and -3.0%, respectively, between 1966 and 2013. The Little Missouri National Grassland (LMNG) in western North Dakota are listed as an important breeding area for the Sprague's pipit, Baird's sparrow, and other grassland birds. Our objectives for this study were to provide a better understanding of the effects of landscape-level (e.g., oil development) and site-specific (e.g., vegetation structure) variables on sensitive grassland bird populations in the LMNG. We surveyed 60 study sites twice each year (2014 and 2015) using a modified transect survey to evaluate grassland bird abundance. The results from this study contributed to understanding grassland bird responses to landscape-level and site-specific variables and identified specific mechanisms by which conservation measures for declining grassland bird populations can be improved.

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TABLE OF CONTENTS

ABSTRACT.....	iii
ACKNOWLEDGMENTS	iv
LIST OF TABLES.....	ix
LIST OF FIGURES	xii
LIST OF APPENDIX TABLES	xiv
1. LITERATURE REVIEW	1
1.1. U.S. Forest service sensitive grassland bird habitat associations.....	1
1.1.1. Baird’s sparrow	1
1.1.2. Sprague’s pipit	3
1.2. The management history of the Little Missouri National Grassland	4
1.3. Relationship between grazing, vegetation structure and composition, and grassland birds	6
1.4. Threats to grassland bird populations.....	8
1.4.1. Habitat loss and fragmentation	8
1.4.2. Livestock grazing.....	9
1.4.3. Invasive or exotic vegetation	11
1.4.4. Anthropogenic disturbance	14
1.5. Project significance	15
1.5.1. Research gaps.....	15
1.5.2. Why are grassland birds important?	17
1.6. References	21
2. GRASSLAND-BIRD RESPONSE TO LANDSCAPE-LEVEL AND SITE-SPECIFIC VARIABLES IN THE LITTLE MISSOURI NATIONAL GRASSLAND.....	40
2.1. Introduction	40
2.1.1. Research questions and objectives.....	43

2.2. Study area	44
2.3. Methods	45
2.3.1. Study design.....	45
2.3.2. Bird census methods	48
2.3.3. Breeding bird populations.....	51
2.3.4. Vegetation sampling	52
2.3.4.1. Structural vegetation sampling	53
2.3.4.2. Vegetation composition	54
2.3.5. Statistical analyses	56
2.4. Results	62
2.4.1. General	62
2.4.2. Modeling results.....	67
2.4.2.1. Grassland bird community	67
2.4.2.2. Sharp-tailed grouse	67
2.4.2.3. Upland sandpiper	72
2.4.2.4. Horned lark	72
2.4.2.5. Sprague's pipit	77
2.4.2.6. Clay-colored sparrow	77
2.4.2.7. Field sparrow	82
2.4.2.8. Vesper sparrow	82
2.4.2.9. Grasshopper sparrow	87
2.4.2.10. Baird's sparrow	87
2.4.2.11. Chestnut-collared longspur	92
2.4.2.12. Bobolink.....	92
2.4.2.13. Western meadowlark	97

2.5. Discussion	100
2.6. Management implications	106
2.7. References	108
APPENDIX.....	125

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1. Covariate abbreviations and corresponding descriptions for landscape and site-specific variables recorded at study sites in the Little Missouri National Grassland in western North Dakota, 2014 and 2015.	58
2. Plausible models using landscape-level variables including well density (Wells), total length of roads (Roads), and percentage grass within 1.6 km of quarter-section edge (Percent.Grass). Refer to Table 1 for covariate descriptions.	61
3. Plausible models using site-specific variables including average visual obstruction reading (AvVOR), percent slope (Slope), Native Floristic Quality Index (Native.FQI), and percentage cover of crested wheatgrass (Percent.AGCR), Kentucky bluegrass (Percent.POPR), bare ground (Percent.BG), and litter (Percent.Litter). Refer to Table 1 for covariate descriptions.	61
4. Summary statistics for 13 explanatory variables collected on 57 sites on the Little Missouri National Grassland in western North Dakota from late-May through mid-August 2014, and 2015.	64
5. Summary statistics for the 20 most frequently observed breeding bird species during surveys conducted on the Little Missouri National Grassland in western North Dakota between 23 May to 25 July 2014 and 19 May to 17 July 2015. The species are ordered by frequency of occurrence.....	66
6. Model-selection results for models relating grassland bird diversity (Shannon [H]) to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC _c). Variable definitions are given in Table 1.....	68
7. Model-selection results for models relating sharp-tailed grouse abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC _c). Variable definitions are given in Table 1.....	70
8. Model-selection results for models relating upland sandpiper abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC _c). Variable definitions are given in Table 1.....	73

9.	Model-selection results for models relating horned lark abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC _c). Variable definitions are given in Table 1.	75
10.	Model-selection results for models relating Sprague's pipit abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC _c). Variable definitions are given in Table 1.	78
11.	Model-selection results for models relating clay-colored sparrow abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC _c). Variable definitions are given in Table 1.	80
12.	Model-selection results for models relating field sparrow abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC _c). Variable definitions are given in Table 1.	83
13.	Model-selection results for models relating vesper sparrow abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC _c). Variable definitions are given in Table 1.	85
14.	Model-selection results for models relating grasshopper sparrow abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC _c). Variable definitions are given in Table 1.	88
15.	Model-selection results for models relating Baird's sparrow sparrow abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC _c). Variable definitions are given in Table 1.	90
16.	Model-selection results for models relating chestnut-collared longspur abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC _c). Variable definitions are given in Table 1.	93

17.	Model-selection results for models relating bobolink abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC_c). Variable definitions are given in Table 1.	95
18.	Model-selection results for models relating western meadowlark abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC_c). Variable definitions are given in Table 1.....	98

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1. Little Missouri National Grassland located within McKenzie, Golden Valley, Billings, and Slope counties in western North Dakota, USA.	44
2. Research sites on the Little Missouri National Grassland in McKenzie, in western North Dakota, USA.....	46
3. Schematic of site transect routes for breeding bird surveys and sampling vegetation structure in the Little Missouri National Grassland in western North Dakota, 2014 and 2015.....	49
4. Observer recording visual obstruction reading using a Robel pole in the Little Missouri National Grassland in western North Dakota.	54
5. The layout of Modified-Whittaker plot used in this study to quantify plant species composition in the Little Missouri National Grassland, 2014 and 2015 (Stohlgren et al., 1995).	56
6. Linear regression plot between mean standing crop (biomass) and mean visual obstruction readings (VOR) with 95% confidence intervals for 60 quarter-section sites in the Little Missouri National Grassland, 2014 and 2015.	62
7. Correlation heatmap with Pearson correlation coefficients for landscape and site-specific covariates (n = 57). Positive correlations are displayed in orange and negative correlations are in brown. Color intensity is proportional to the correlation.....	63
8. Model results showing relationship (black line with red-dashed 95% confidence intervals) between grassland bird diversity (Shannon [H]) and percentage grassland and visual obstruction reading (cm).....	69
9. Model results showing relationship (black line with red-dashed 95% confidence intervals) between sharp-tailed grouse abundance and well density and litter depth (cm). Only strongly supported relationships are shown.	71
10. Model results showing relationship (black line with red-dashed 95% confidence intervals) between upland sandpiper abundance and percentage grassland and bare ground.	74
11. Model results showing relationship (black line with red-dashed 95% confidence intervals) between horned lark abundance and litter depth.	76
12. Model results showing relationship (black line with red-dashed 95% confidence intervals) between Sprague's pipit abundance and road length and visual obstruction reading.....	79

13.	Model results showing relationship (black line with red-dashed 95% confidence intervals) between clay-colored sparrow abundance and percentage grassland, well density, and FQI.....	81
14.	Model results showing relationship (black line with red-dashed 95% confidence intervals) between field sparrow abundance and percentage grassland and crested wheatgrass.....	84
15.	Model results showing relationship (black line with red-dashed 95% confidence intervals) between vesper sparrow abundance and well density and FQI.	86
16.	Model results showing relationship (black line with red-dashed 95% confidence intervals) between grasshopper sparrow abundance and slope.....	89
17.	Model results showing relationship (black line with red-dashed 95% confidence intervals) between Baird's sparrow abundance and road length and slope.	91
18.	Model results showing relationship (black line with red-dashed 95% confidence intervals) between chestnut-collared longspur abundance and percentage grassland and visual obstruction reading.	94
19.	Model results showing relationship (black line with red-dashed 95% confidence intervals) between bobolink abundance and slope.....	96
20.	Model results showing relationship (black line with red-dashed 95% confidence intervals) between western meadowlark abundance and road length, well density, and percentage bare ground.	99

LIST OF APPENDIX TABLES

<u>Table</u>	<u>Page</u>
A1. Legal land description (Township, Range, Section and Quarter) and area (ha) of 60 study sites in the McKenzie District of the Little Missouri National Grassland in western North Dakota, 2014 and 2015..	126
A2. Densities (breeding pairs / 100 ha) averaged across years of 82 bird species observed during surveys conducted on the Little Missouri National Grassland between 23 May to 25 July 2014 and 19 May to 17 July 2015. The species are in taxonomic order.....	127
A3. Plant species observed on 171 modified Whittaker plots on 57 study sites in the Little Missouri National Grassland, 2014 and 2015. Floristic composition was measured only once in the two field seasons, one-half of the study sites in the first year and one-half during the second year. Non-native species are not assigned a C value. The species are in alphabetical order..	130
A4. Summary of average measurements of vegetation composition variables on sites in the Little Missouri National Grassland in western North Dakota, 2014 and 2015.....	138

1. LITERATURE REVIEW

1.1. U.S. Forest service sensitive grassland bird habitat associations

1.1.1. Baird's sparrow

The Baird's sparrow (*Ammodramus bairdii*) was one of the most common birds on the northern mixed-grass prairie prior to European settlement (Green, 2002) and is now considered a species of notable conservation concern in Regions 2 and 6 of the U.S. Fish and Wildlife Service (USFWS, 2008). In a 9-month finding on a petition to list the Baird's sparrow as "Endangered" or "Threatened" under the Endangered Species Act (1973), the USFWS concluded that the listing of Baird's sparrow was not justified because the petition did not present substantial information indicating that the listing of this species as threatened was warranted (USFWS, 1999). The species also is listed as a "Sensitive Species" in Region 1 (Northern Region) of the U.S. Forest Service (USFS, 2005). The USFS defines sensitive species as species that need special management to maintain and improve their status on National Forests and Grasslands, and prevent a need for listing under the Endangered Species Act (USFS, 2005). The North Dakota Game and Fish Department (NDGFD) listed the Baird's sparrow as a "Level 1 Species of Concern" in the North Dakota State Wildlife Action Plan (Dyke and Isakson, 2015).

Baird's sparrows tend to favor idle native or introduced grasslands and lightly to moderately grazed pastures (Owens and Myres, 1973; Stewart, 1975; Kantrud and Kologiski, 1982; Skeel et al., 1995; De Smet and Conrad, 1997). The species sometimes uses planted cover (e.g., Conservation Reserve Program [CRP] and dense nesting cover), dry wetland basins, wet meadows, and dense stands of grass within hayland and cropland (Lane, 1968; Stewart, 1975; Johnson and Schwartz, 1993). Several studies have highlighted the importance of native prairie to Baird's sparrow breeding habitat (Cartwright et al., 1937; Lane, 1968; Owens and Myres,

1973; Dale, 1992; Dale et al., 1997), and some studies have shown that Baird's sparrows exhibit a preference for native grasses (Winter, 1994; Sutter et al., 1995; Madden, 1996). However, some studies have shown that Baird's sparrows respond more strongly to vegetative structure than plant species composition in Canada and did not exhibit a preference for native grasslands (Anstey et al., 1995; Sutter et al., 1995; Davis et al., 1999).

General habitat requirements for Baird's sparrow include moderately deep litter; moderate vegetation height; moderately high, but patchy forb coverage; patchy grass and litter cover; and little woody vegetation (Dechant et al., 2003). In northern mixed-grass prairies in North Dakota, Baird's sparrows were present in grasslands with higher litter depth and a lower percentage of live vegetation than in unoccupied areas (Grant et al., 2004). In North Dakota, the probability of Baird's sparrow occurrence increased with grass cover, forb cover, and native grass frequency, reaching 50% occurrence at 42% grass cover, 35% forb cover, and 0.42 native grass frequency (Madden et al., 2000). Baird's sparrows also occupied areas with significantly greater grass cover than unoccupied areas (Madden, 1996). In contrast, Baird's sparrow abundance in grazed mixed-grass prairies in North Dakota was negatively associated with the percentage of grass cover at the site-level, whereas abundance was positively associated with plant communities dominated solely by native grass (*Hesperostipa*, *Bouteloua*, *Koeleria*, and *Schizachyrium*) (Schneider, 1998). Another study in northern mixed-grass prairies found that the Baird's sparrow was present in grasslands with higher percentage cover of Kentucky bluegrass (*Poa pratensis*) than in unoccupied areas and that Baird's sparrow occurrence was not related to coverage of native grass and forb species, tame legumes, smooth brome (*Bromis inermis*) and quackgrass (*Elymus repens*) (Grant et al., 2004).

1.1.2. Sprague's pipit

The Sprague's pipit also is one of the few grassland bird species endemic to the northern Great Plains (Mengel, 1970), and is one of the least understood bird species in North America due to its small breeding range, as well as its cryptic plumage and secretive behaviors (Robbins and Dale, 1999). Sprague's pipit was a candidate for listing as "Endangered" or "Threatened" under the Endangered Species Act (1973), but the USFWS recently withdrew it from the candidate list (USFWS, 2016). Sprague's pipit is considered a "Sensitive Species" in Region 1 (Northern Region) of the USFS (2005). It also is listed as a "Level 1 Species of Concern" in North Dakota's State Wildlife Action Plan (Dyke and Isakson, 2015).

Several researchers have found that Sprague's pipits are closely associated with native grasslands throughout their breeding range (Sutter, 1996; Sutter and Brigham, 1998; Madden et al., 2000; Grant et al., 2004) and are less abundant in areas of introduced grasses than in areas of native prairie (Kantrud, 1981; Johnson and Schwartz, 1993; Dale et al., 1997; Madden et al., 2000; Grant et al., 2004). Generally, Sprague's pipits prefer higher grass and sedge cover, less bare ground, and an intermediate average grass height when compared to the surrounding landscape, <5-20% shrub and brush cover, no trees at the territory scale, and litter cover <12 cm (Sutter, 1996; Madden et al., 2000; Dieni and Jones, 2003; Grant et al., 2004).

As with other grassland birds, vegetative structure figures prominently in habitat selection by Sprague's pipit during the breeding season. In North Dakota mixed-grass prairies, Sprague's pipits were present in grasslands with lower litter depth, lower maximum vegetation height, lower percentage cover of shrubs greater than 1 m tall, and lower percentage cover of shrubs less than 1 m tall than in unoccupied grasslands (Grant et al., 2004). Another North Dakota study found that visual obstruction (i.e., vegetation height-density) was the best predictor

of Sprague's pipit occurrence (Madden et al., 2000). Sprague's pipits also were found to avoid idle areas with deep litter (Madden, 1996). In northwestern North Dakota, male breeding territories were located on ridgetops with low sedge and forb densities and short grass (Robbins, 1998). In a study on the Grand River National Grassland (GRNG) in northwestern South Dakota, Sprague's pipits were present on sites that had the following characteristics: close proximity to shrubs, deeper litter, slightly higher altitudes, and higher stocking rates than unoccupied grasslands (Winter, 2007). Litter depth was shown to be the best predictor for the presence of Sprague's pipits on the GRNG (Winter, 2007).

1.2. The management history of the Little Missouri National Grassland

Although the National Grasslands were not officially designated until 1953 (Dana, 1980), the events which would spur their creation can be traced back to the mid-1800s when Congress enacted the Homestead Act (1862). The Homestead Act authorized the dispersal of 160-ac (i.e., 64.7-ha) parcels of federal land to qualified individuals in an attempt to accelerate the settlement of the Great Plains. However, much of this land was "submarginal," which led to a large number of failed farms (Aileen, 1995). Recognizing their error, Congress began investigating the issues related to submarginal lands plaguing the Great Plains in the 1920s. The resulting legislation—the National Industrial Recovery Act (1933) and the Emergency Relief Act (1935)—spurred the purchase of these "submarginal" farmlands, which became known as Land Utilization Projects (LUP). LUP lands were administered and managed by several agencies until 1938, when they were transferred to the Soil Conservation Service (SCS)—now known as the Natural Resource Conservation Service (NRCS). Under the management of the SCS, LUP lands underwent several management changes that would shape these lands into the present-day National Grasslands. Many areas that had recently been plowed under the direction of the Homestead Act

were reseeded with crested wheatgrass (*Agropyron cristatum*), a non-native plant that originated from Russia (Johnson, 1986; Aileen, 1995; Moul, 2006). Perhaps the most influential management decision came when the SCS extended grazing privileges to private landowners (Aileen, 1995).

Grasslands like the Little Missouri National Grassland (LMNG) are primarily maintained by climatic variations, in particular drought (Biondini et al., 1998); however, grazing and fire also are important drivers of these grassland ecosystems (Askins et al., 2007). The historical interactions between climate, American bison (*Bison bison*) grazing, and fire, maintained a heterogeneous landscape, which provided habitat for several species of obligate grassland birds (Askins et al., 2007). The near-extinction of American bison and the resulting shifts in grazing practices has likely contributed to recent grassland bird population declines (Askins et al., 2007).

Historically, grazing by native mammals occurred naturally across much of the northern Great Plains (Lauenroth et al., 1994). Native ungulates, such as American bison, pronghorn (*Antilocapra americana*), and elk (*Cervus elaphus*), were the prominent grazing mammals on the Great Plains post-Pleistocene. However, colonial rodents, such as prairie dogs (*Cynomys* spp.) and ground squirrels (e.g., *Urocitellus richardsonii*, *Ictidomys tridecemlineatus*, *Poliocitellus franklinii*) and the now extinct Rocky Mountain locust (*Melanoplus spretus*), also were major components of the historic grazing system of the Great Plains. The historical interactions between fire and American bison resulted in a shifting mosaic of heavily grazed and undisturbed grassland patches (Fuhlendorf and Engle, 2004). Modern livestock management goals place an emphasis on maximizing forage utilization by strategically placing fencing, minerals, and water sources (Coughenour, 1991), and thus, creating a more homogenous landscape that is contrary to historic disturbance regimes (Fuhlendorf and Engle, 2001). However, habitat heterogeneity can

be achieved if the selective grazing habits of cattle are implemented using lower stocking rates on larger pastures (Hart et al., 1993). Landowners have an economic incentive for heavier grazing on their lands because beef production increases with an increase in stocking rate and grazing pressure (Derner et al., 2009), although they risk the deterioration of rangelands and diminishing economic returns (Hart et al., 1988). This is not to say that patches of shorter-structured grasslands do not have a place in contemporary grassland ecosystems. Historically, American bison would preferentially select high-quality vegetation regrowth within recently burned portions of the landscape (Coppedge and Shaw, 1998). These recently burned patches of grassland would experience bouts of intensive grazing, while adjacent unburned patches received less grazing pressure (Fuhlendorf and Engle, 2001). Given that the community of grassland birds that evolved within the Great Plains requires a gradient of vegetation structure (Samson and Knopf, 1994; Fuhlendorf et al., 2006; Hovick et al., 2015), it is just as important to manage for grassland bird species at both extremes of this gradient as well as in between. For example, the long-billed curlew (*Numenius americanus*) prefers sparser vegetation (Dechant et al., 2002), whereas the Baird's sparrow prefers taller and denser vegetation (Dechant et al., 2003). Although there are many differences between historic ungulate grazing and modern cattle management, cattle can be an appropriate substitute for native ungulates when managing for grassland birds (Plumb and Dodd, 1993; Knapp et al., 1999; Derner et al., 2009).

1.3. Relationship between grazing, vegetation structure and composition, and grassland birds

Livestock grazing modifies habitat structure and plant communities in a number of different ways. Grazing reduces plant canopy height, changes plant morphology, creates grazing lawns, affects hydrology, compacts the soil, and changes the rate of litter accumulation

(Milchunas et al., 1989; Saab et al., 1995; Hartnett et al., 1997). Livestock also impact areas where they do not actively remove plant material by compacting the soil and indirectly creating bare ground (Hartnett et al., 1997). Livestock grazing also has direct impacts on the composition of plant species (Collins, 1987; Anderson and Briske, 1995), and therefore on habitat structure, due to the selection for or avoidance of certain plant species (Briske et al., 2005). These species-specific impacts can affect habitat structure because taller species that are grazed will lose dominance, allowing short-stature species to increase in abundance (Anderson and Briske, 1995). When the abundance of dominant grasses is reduced by disturbances such as grazing, the growth and survival of subdominant species can increase the diversity and evenness of the plant community (Cid et al., 1991; Hartnett et al., 1997).

Grazing intensity also influences plant diversity on rangelands. Several studies have found that diversity, richness, and evenness were highest on pastures that were lightly to moderately grazed (Collins and Barber, 1986; Hartnett et al., 1996; Collins et al., 1998; Knapp et al., 1999). Other studies concluded that diversity can either increase or decrease with grazing depending on a suite of factors, including the productivity of the grassland, the intensity of grazing, and the evolutionary history of grazing in the area (Milchunas et al., 1988, 1998; Cid et al., 1991; Bakker et al., 2006). Increased grazing intensity mainly affects grassland birds through reduced vegetation structure (i.e., lower vegetation height and density), decreased standing dead vegetation, and decreased litter accumulation (Biondini et al., 1998; Gillen et al., 2000).

The aforementioned studies have found that livestock grazing has played a large role in the structuring of grasslands. Because grassland breeding birds select sites primarily based on vegetation structure (Wiens, 1969; Fisher and Davis, 2010), it is likely that grazing affects the

occurrence and abundance of grassland birds (Davis et al., 2009). Therefore land management practices—like grazing—has the potential to increase the heterogeneity of grasslands (e.g., pyric-herbivory) and may be beneficial to grassland birds that have differing vegetative structure preferences (Fuhlendorf et al., 2006).

1.4. Threats to grassland bird populations

Since 1966, 24 grassland obligate breeding birds have declined by nearly 40% (Sauer et al., 2014). Although these declines began to stabilize in the early 1990s, a sub-group of grassland birds—including Sprague’s pipit and Baird’s sparrow—continue steep declines (Sauer et al., 2014). Several hypotheses have been proposed to explain these declines, including conversion of prairie to agriculture-dominated landscapes and prairie fragmentation (Knopf, 1994); historic livestock grazing (Saab et al., 1995); rangeland deterioration (e.g., overgrazing, drought, fire suppression, and woody plant and exotic plant invasions) (Brennan and Kuvlesky, 2005); and anthropogenic disturbances, such as oil development and associated access roads (Hamilton et al., 2011; Ludlow et al., 2015; Thompson et al., 2015)

1.4.1. Habitat loss and fragmentation

Grassland conversion has reduced the quality and availability of suitable habitat for area sensitive species, such as Sprague’s pipit and Baird’s sparrow. Sprague’s pipit prefers large patches of grassland, with a minimum size requirement of about 145 ha, whereas the Baird’s sparrow has a minimum size requirement of about 25 ha (Davis and Brittingham, 2004). In the northern Great Plains agricultural conversion is happening five times faster than grasslands are being protected (Doherty et al., 2013; Walker et al., 2013). From 1997-2007, approximately 1% of grasslands were converted to crop production in the Great Plains (roughly 311,608 ha), whereas only 40,469 ha of cropland reverted back to grassland during this same time period

(Claassen et al., 2011). During this period, many agricultural producers took highly erodible, tillable land out of agricultural production and planted it to perennial grassland cover to help improve water quality and prevent soil erosion, via the Conservation Reserve Program (CRP) (FAPRI, 2007). A secondary objective of the CRP was to provide habitat for wildlife (Johnson, 2000). Between 1997 and 2007, roughly 1.4 million ha of cropland was placed into CRP (Claassen et al., 2011). Several researchers reported that Sprague's pipits and Baird's sparrows rarely used CRP grassland fields or other seeded cover planted for waterfowl production (Johnson and Schwartz, 1993; Prescott and Davis, 1998) and therefore these programs do little to mitigate the effects of grassland conversion on populations of Sprague's pipit or Baird's sparrow. However, CRP did benefit other grassland birds (e.g., grasshopper sparrow; Johnson and Igl, 1995; Johnson, 2000). Baird's sparrow and Sprague's pipit often are associated with native prairie (Sutter, 1996; Madden et al., 2000; Davis and Brittingham, 2004), but will occasionally use non-native grasslands that were previously cultivated if the vegetation structure is suitable (Dale et al., 1997; Sutter and Brigham, 1998).

1.4.2. Livestock grazing

Livestock grazing occurs on more than 300 million ha in the United States each year, making it one of the most widespread causes of landscape modification in the nation (Hobbs, 1996). In a study of the effects of grazing intensity on floral and faunal communities on the shortgrass steppe of Colorado, the only group of animals found to have shifted in dominant species and community composition in response to grazing intensity were grassland birds (Milchunas et al., 1988). These results emphasize that birds are particularly sensitive to grazing treatments. Because different grassland birds have different habitat requirements (Saab et al.,

1995; Askins et al., 2007), there is a need to manage grazing to provide suitable habitat for multiple species (Samson and Knopf, 1996).

Grazing has a substantial influence on the structuring of grasslands in the northern Great Plains (Milchunas et al., 1988; Knopf, 1994), and, therefore, greatly influences sensitive grassland bird occurrence and abundance (Prescott and Davis, 1998). The effects of livestock grazing on the abundance and distribution of Sprague's pipits and other grassland birds depend on several factors, including livestock stocking rates, as well as environmental conditions, such as moisture, soil type, and plant species composition (Owens and Myres, 1973). Therefore, the response of grassland birds to grazing intensity and frequency likely varies by region.

Although several studies have found that Sprague's pipits tend to avoid heavily grazed grasslands (Maher, 1973; Owens and Myres, 1973; Prescott and Wagner, 1996), lightly to moderately grazed grasslands have been identified as optimal habitat for Sprague's pipits throughout much of their breeding range (Owens and Myres, 1973; Davis et al., 1999; Robbins and Dale, 1999). In North Dakota, Kantrud (1981), reported a greater abundance of Sprague's pipits in grasslands that were moderately- to heavily-grazed. In the mesic mixed-grass prairie, disturbances such as fire at appropriate intervals and grazing at appropriate rates can be used to create and maintain Sprague's pipit habitat (Kantrud, 1981; Madden et al., 1999). In the drier, less densely-vegetated mixed-grass prairie in the southwestern portions of Sprague's pipit range, some studies have shown that Sprague's pipit abundance decreased significantly with increasing grazing intensity (Maher, 1973; Dale, 1984; Robbins and Dale, 1999).

In both the moist and drier parts of the Baird's sparrow breeding range, heavy or continuous grazing that reduces residual vegetation and litter was found to be detrimental to breeding populations of Baird's sparrow (Owens and Myres, 1973; Kantrud, 1981; Anstey et al.,

1995). However, Davis and others (1999) found that grazing intensity did not dramatically impact Baird's sparrow abundance, yet Baird's sparrows were still attracted more to pastures with relatively taller vegetation and lower shrub cover. In general, grazing systems which provide moderate vegetative and litter cover are suitable for Baird's sparrows (Anstey et al., 1995). Messmer (1990) found higher numbers of Baird's sparrows in pastures that implemented a rotational grazing system, than in pastures that experienced season-long grazing or short-duration grazing. In Alberta, however, Baird's sparrow presence did not significantly differ between four different grazing treatments: early-season tame (grazed from late April to mid-June); early-season native (grazed in early summer); deferred-grazed native (grazed after 15 July); and, season-long grazed native (Prescott and Wagner, 1996). Like other grassland birds, the factors that influence the occurrence of Baird's sparrows can vary by region or environmental conditions (Maher, 1973; Owens and Myres, 1973). In denser, taller habitats, or during wet years, light-to-moderate grazing can improve habitat by providing shorter, sparser vegetation (Kantrud, 1981; Messmer, 1990; Anstey et al., 1995). In Saskatchewan, over-stocking livestock nearly eliminated Baird's sparrows from the landscape during a drier than normal breeding season (Dale, 1984). However, following a moist winter and spring, new growth on grazed pastures was twice the height of the previous season's growth and Baird's sparrow populations rebounded in the area.

1.4.3. Invasive or exotic vegetation

Smooth brome and Kentucky bluegrass were planted as part of the U.S. Department of Agriculture Soil Bank Program in the 1950s and 1960s, the Cropland Adjustment Program in the 1960s (Duebbert et al., 1981), and more recently the CRP beginning in 1985 (Johnson, 2000; Fargione et al., 2012). Although the primary objectives of these Farm Bill programs were to

conserve soil and water resources, an additional benefit was realized—the creation of wildlife habitat. The resulting mixed stands of native and exotic grasses and forbs provided some wildlife species refuge from the surrounding cropland-dominated landscape of the northern Great Plains (Johnson and Igl, 1995; Johnson, 2000). One benefit of these mixed plantings is the highly palatable seeds of smooth brome, which provide valuable forage for upland gamebirds and songbirds (Sedivec and Barker, 1997). Although there were some benefits from planting cool-season grasses for grassland birds, there also were some negative consequences. Smooth brome and Kentucky bluegrass spread from these and other plantings and invaded adjacent native prairie tracts (DeKeyser et al., 2013), potentially causing shifts in grassland songbird communities (Grant et al., 2006).

There is evidence which suggests that grassland birds show an affinity for exotic vegetation stands, although other grassland birds have had shown a negative response. For example, grasshopper sparrow (*Ammodramus savannarum*), clay-colored sparrow (*Spizella pallida*), and vesper sparrow (*Pooecetes gramineus*) showed a preference for stands dominated by smooth brome and Kentucky bluegrass (Wilson and Belcher, 1989). However, this apparent preference for non-native vegetation may reflect these species affinity for mesic grasslands (Madden et al., 2000). On the other hand, some grassland birds, including upland sandpiper (*Bartramia longicauda*), Sprague's pipit, western meadowlark (*Sturnella neglecta*), Baird's sparrow, bobolink (*Dolichonyx oryzivorus*), and Savannah sparrow (*Passerculus sandwichensis*), have shown a preference for native vegetation stands (Wilson and Belcher, 1989; Madden et al., 2000). Overall, studies of grassland bird habitat preferences have had mixed and often contradictory results. However, researchers tend to agree that the increasing amount of exotic

vegetation is causing grassland bird populations to decline because of two factors: 1) reduced fitness, and 2) loss of vegetative heterogeneity.

Several studies show that the invasion of exotic vegetation can have adverse reproductive consequences for native animals (Schmidt and Whelan, 1999; Remeš, 2003; Lloyd and Martin, 2005). In Montana, for example, researchers found that the chestnut-collared longspur (*Calcarius ornatus*) did not prefer native vegetation over exotics (Lloyd and Martin, 2005). Longspurs nested at similar densities in both native and exotic habitats, and individuals did not appear to differentiate between the two habitats when establishing breeding territories in the spring. However, breeding success may be a better indicator of habitat quality. Lloyd and Martin (2005) found that reproductive success was lower in monocultures of exotic grass than in native prairie. They also reported that the odds of a nest surviving on native prairie sites were approximately 17% higher than exotic prairies, primarily due to increased nest predation on exotic sites.

Although several studies suggest that grassland songbirds have a preference for native habitat, there is still little evidence that vegetation community composition has a consistent influence on grassland-bird habitat use (Fisher and Davis, 2010). Instead, vegetation structure may play a larger role in grassland songbird habitat selection. Grasslands with heterogeneous structure are essential for grassland songbird diversity (Madden et al., 2000). Invasive cool-season grasses can decrease the structural composition in prairies by outcompeting native plant species and reducing species diversity that naturally creates a mosaic across the landscape (Hendrickson and Lund, 2010). The loss of vegetative structure also favors generalist species that can tolerate habitat homogeneity, therefore supporting a bird community that is less diverse than on a native prairie site (Toledo et al., 2014).

1.4.4. Anthropogenic disturbance

As global human populations continue to expand at a growth rate of 1.18% per year (i.e., approximately 83 million people annually) (UNDESA, 2015), resource exploitation is likely to continue to stress natural ecosystems, resulting in more habitat degradation and loss of biodiversity (Tilman et al., 2001). Recent population declines of grassland birds often are linked to direct habitat loss and degradation due to agricultural activities, fire suppression, and industrial and urban development (Samson and Knopf, 1994; Brennan and Kuvlesky, 2005; Askins et al., 2007). Previous research has identified a variety of sources of habitat degradation, with activities associated with energy development receiving modest attention, despite the growing number of regions affected (Dale, 1984; Askins et al., 2007). The previously inaccessible fossil fuels in the shale rock formations of the Williston Basin and Bakken formations in western North Dakota are now being extracted with new, unconventional technologies, such as hydraulic fracturing (i.e., fracking) (EIA, 2011). The North Dakota Industrial Commission (2012) predicted that 2,000 new oil wells will be drilled annually from 2014 to 2034. The Bakken formation coincides with areas of unusually high grassland bird abundance and diversity (Peterjohn and Sauer, 1999). The rapid expansion of oil development in North Dakota exacerbates conservation concerns for grassland birds that breed in the Bakken region, because many of them have experienced long-term population declines (Peterjohn and Sauer, 1999), and have demonstrated sensitivity to habitat fragmentation (Reino et al., 2009; Ribic et al., 2009) and disturbances related to oil development (Hamilton et al., 2011; Thompson et al., 2015).

In western North Dakota, Thompson and colleagues (2015) found that several species of grassland birds avoid oilfield infrastructure, including secondary access roads. The study

reported reduced avian densities near roads may have resulted from heavy traffic associated with oil development in the region (Thompson et al., 2015). In grasslands of southern Alberta, Sprague's pipits did not appear to avoid low-traffic roads (Koper et al., 2009). However, sagebrush-obligate songbirds in Wyoming are significantly less common within 100 m of roads associated with oil development (Ingelfinger and Anderson, 2004). Roads associated with oil and natural gas extraction tend to experience considerably higher traffic volume than roads in most other comparable locations (Fershee, 2012). In lightly to moderately grazed native prairie in Saskatchewan, Sprague's pipits and Baird's sparrows were more abundant in grasslands alongside trails (i.e., single pair of wheel ruts) than in grasslands alongside roads (i.e., traveling surfaces with adjacent drainage ditches planted to exotic vegetation and ending with a fence 11-18 m from the traveling surface) (Sutter et al., 2000).

1.5. Project significance

1.5.1. Research gaps

There is little information regarding the distribution and abundance of bird species within the LMNG, highlighting the importance of developing monitoring programs with the aim to understand population trends and underlying factors contributing to such trends (Sparks et al., 2009). At a continental scale, the Breeding Bird Survey (BBS) offers the most extensive data on bird distributions and population trends (Robbins et al., 1989). The BBS has relatively sparse coverage in the northern Great Plains region and the restriction of survey routes to roadways leads to inadequate sampling for sensitive species, such as the Sprague's pipit (O'Connor et al., 2000). The BBS also does not reliably predict population trends at small geographic scales such as the LMNG (Sauer, 1995). For these reasons, BBS data are generally insufficient to guide local and regional management decisions (Leukering et al., 2000), such as those by National

Grassland managers. Sparks and Hanni (2009) attempted to fill this knowledge gap by surveying breeding birds on 31 transects on the Little Missouri, Sheyenne, and Grand River National Grasslands. The objectives of their monitoring program were to determine population trends and distributions for breeding birds on the Dakota Prairie Grasslands. However, their study did not explore the specific habitat features that were associated with the occurrence of the species. In addition, one of their site-selection criteria was a “minimum road access network.” Thus, the effects of roads on breeding grassland birds were not explored.

Davis (2009) examined the breeding biology of Sprague’s pipits in Saskatchewan, Canada. Although Davis’ (2009) study provided important information about Sprague’s pipit life-history parameters, it did not quantify the specific habitat features that are associated with the occurrence of the Sprague’s pipit. Dieni and Jones (2003) explored nest-site selection patterns of six grassland birds in north-central Montana. The main objective of that study was to discern habitat differences at a smaller scale (i.e., nesting site). However, they did not explore landscape-level or site-specific variables that grassland birds use during their hierarchical selection of a breeding site (Johnson, 1980). Winter (2007) examined the distribution and habitat associations of sensitive grassland birds on the Grand River National Grassland, which like the LMNG, is located within the Dakota Prairie Grasslands. Winter recommended that similar studies be conducted to strengthen understanding of habitat management on sensitive grassland birds.

Several studies have explored the effects of oil extraction on grassland birds (Hamilton et al., 2011; Bogard and Davis, 2014; Ludlow et al., 2015). However, as Thompson (2015) points out, many of these studies were conducted in areas with more conventional oil development, whereas the oil development in North Dakota uses unconventional practices such as hydraulic

fracturing. Infrastructure associated with hydraulic fracturing generally has different maintenance requirements (e.g., higher traffic levels), and therefore has different effects on the landscape than other, more traditional oil-extraction methods (Thompson et al., 2015).

The study presented herein will build upon earlier studies to provide a better understanding of the effects of landscape-level (e.g., percent grassland in surrounding landscape) and site-specific (e.g., slope, litter depth) variables on sensitive grassland bird populations and grassland bird diversity and community composition in the LMNG. This study also will provide information on how oil development in western North Dakota may be affecting grassland birds in the region. The results from this study will contribute to understanding grassland songbird responses to landscape-level and site-specific variables and identify specific mechanisms by which conservation measures for declining grassland bird populations can be improved.

1.5.2. Why are grassland birds important?

Biodiversity is the sum total of all biotic organisms on Earth, including their genetic and phenotypic variation, and the communities and ecosystems in which they occur (Swingland, 2001). The Earth is currently experiencing its richest and most varied biodiversity in geologic history, due to a long history of speciation (Rosenzweig, 1995); however, biodiversity is being threatened by an increasing extinction rate (May et al., 1995). Darwin (1872) was one of the first to acknowledge the importance of biodiversity, noting that several distinct genera of grasses grown together would produce more biomass than a single species growing alone. It is well documented that biodiversity losses result in ecosystem instability (Tilman, 1996; Jiang and Pu, 2009; Hector et al., 2010). Biodiversity can stabilize ecosystem productivity, and field studies have confirmed that plant species-rich plots showed less yearly variation in primary productivity (Tilman, 1996) and that productivity during a drought year declined much less in those plots than

in species-poor plots (Tilman and Downing, 1994). The diversity within a functional group—such as grassland birds—is often just as important as overall species diversity (Kremen, 2005). This is not to say that individual, less abundant species are of less importance. Rare species often are overlooked but can provide an extra buffer against disturbance, environmental change, and the loss of more dominant species (Hobbs et al. 2007). The role of rare species—like the Baird’s sparrow and Sprague’s pipit—are important to environments where species abundances vary temporally. In these environments, rare species can contribute significantly to long-term and large-scale ecosystem functioning (Lyons et al., 2005). Ehrlich and Ehrlich (1981) offered an analogy that highlights the importance of less abundant species within an ecosystem. They compared rare species to rivets on an airplane wing. While a few missing rivets may go unnoticed, there will be a threshold at which the wing cannot lose any more rivets and a catastrophe will ensue.

Biodiversity also plays a large role in the provision of ecosystem services, although this is often a point of contention among ecologists. However, it is well documented that increased biodiversity improves ecosystem services (Minns et al., 2001; Sax and Gaines, 2003). Ecosystem services are any set of ecosystem functions that are helpful to humans. They can be critical to human life (e.g., climate regulation, air purification, crop pollination) or enhance it (e.g., aesthetics). The best, and possibly most well-known example of an ecosystem service is pollination. Honeybees (*Apis*) pollinate much of the Earth’s crops, which in turn provide a service that benefits humans via the production of food. Ecosystem services provided by birds, however, are not quite as obvious. Early ornithological research in the U.S. in the late 1800’s and early 1900’s focused on the economic impact of birds on agriculture (e.g., Barrows, 1889; Judd, 1901). Birds were once thought to contribute little to overall ecosystem productivity

(Wiens, 1973; Holmes and Sturges, 1975), but we now know that birds serve many purposes, including predation, pollination, scavenging, seed dispersal, seed predation, and ecosystem engineering (Sekercioglu, 2006; Whelan, et al., 2015).

There are four principal types of ecosystem services: provisioning, regulating, cultural, and supporting. Perhaps one of the most important services—both monetarily and aesthetically—is birdwatching or “birding.” Birdwatchers are one of the best sources of ecotourism income since they form the largest single group of ecotourists, are educated, and have above average incomes (Cordell and Herbert, 2002). In 2011, there were an estimated 47 million birders in the United States—approximately 20% of the country’s population (USFWS, 2011). Birders spend money on a variety of goods and services for their trip-related and equipment-related purchases. Birding-related expenses ripple through the economy by impacting economic activity, employment, and household income. In 2011, birders spent an estimated \$15 billion on their trips and \$26 billion on equipment. In addition, birding generated approximately 666,000 jobs, and \$13 billion in local, state, and federal tax revenue (USFWS, 2011). Birdwatching also has important conservation impacts. At a broad-scale, the growing popularity of birdwatching and their outreach has led other groups of society to consider birds. For example, consumers may be willing to pay a premium for agricultural products certified as bird-friendly (Rice, 2010). Birdwatchers actively participate in citizen science, such as the BBS (Robbins et al., 1989), the Christmas Bird Count (Dunn et al., 2005), and eBird (Sullivan et al., 2014). Because of their exposure to citizen science, birders tend to be more aware of environmental issues, and thus, they are more likely to support habitat conservation that benefits bird populations (Kronenberg, 2014). Ecotourism also provides an incentive to locals to protect sensitive bird habitat. This is

evident in the growing number of private nature preserves where suitable bird habitat is protected in order to obtain income from tourists seeking to view a specific bird (Aylward et al., 1996).

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2. GRASSLAND-BIRD RESPONSE TO LANDSCAPE-LEVEL AND SITE-SPECIFIC VARIABLES IN THE LITTLE MISSOURI NATIONAL GRASSLAND

2.1. Introduction

Grasslands are one of the most endangered ecosystems in the world (Noss et al., 1995), so it is not surprising that grassland obligate birds have experienced the steepest, most consistent, and most geographically widespread declines of any North American birds (Knopf, 1994; Herkert, 1995; Igl and Johnson, 1997). Although populations of some grassland birds have stabilized at low levels in recent years, many grassland species have continued to decline (NABCI, 2014). The Sprague's pipit (*Anthus spragueii*) and Baird's sparrow (*Ammodramus bairdii*)—grassland birds that breed exclusively in the northern Great Plains (Mengel, 1970)—are of particular concern. Wells (2010) described the pipit as “one of the fastest declining songbirds of North America.” Sprague's pipits also are considered one of the least known bird species in North America, due to their restricted breeding range, cryptic plumage, and secretive behaviors (Robbins and Dale, 1999). Trend analysis from the North American Breeding Bird Survey (BBS) indicated that populations of Sprague's pipit and Baird's sparrow have experienced severe annual declines of -3.5% and -3.0%, respectively, between 1966 and 2013 (Sauer et al., 2014).

In a 12-month finding on a petition to list the pipit as endangered or threatened, the U.S. Fish and Wildlife Service (USFWS) concluded that the listing of the Sprague's pipit is warranted but is currently precluded by higher priority actions (USFWS, 2010). Based on the 12-month finding, the USFWS proposed the Sprague's pipit for listing as a candidate species under the Endangered Species Act. However, a recent status review of the Sprague's pipit prompted the USFWS to withdraw the species from the candidate list (USFWS, 2016). The USFWS declined

an earlier petition to list the Baird's sparrow as threatened in 1999 because the petition did not present substantial information indicating that the listing of this species as threatened was warranted (USFWS, 1999). Both species also are included on several lists of "species of high conservation concern" by federal (e.g., USFS, 2005) and state agencies (e.g., North Dakota [Dyke et al., 2015], South Dakota [SDGFP, 2014], and Minnesota [MNDNR, 2006]) and nongovernment organizations (e.g., Partners in Flight; [Rich et al., 2004]).

The Sprague's pipit and Baird's sparrow are both considered area sensitive species that require a minimum patch size of 145 ha and 25 ha, respectively (Davis and Brittingham, 2004). Less than 18% of native grassland remains in the current breeding range of both species (Samson and Knopf, 1994; Noss et al., 1995). Large-scale losses—largely from conversion to cropland—and degradation of critical grassland habitat highlight the importance of enhancing remnant prairies and restored grasslands (Samson and Knopf, 1994). Some of the largest remaining native grassland patches in the United States portion of the northern Great Plains occur on the Little Missouri National Grassland (LMNG), which is administered and managed by the U.S. Forest Service (USFS). The USFS currently administers 20 National Grasslands, encompassing about 1.5 million ha of federal land in 13 states (Olson, 1997). The majority of the National Grasslands are found in the Great Plains states of Colorado, North Dakota, South Dakota, and Wyoming. National Grasslands in these four states alone account for 1.3 million ha (82%) of the total area of National Grasslands. The LMNG also was listed as one of the most important breeding areas for the Sprague's pipit (Wells, 2010)—further highlighting the importance of the LMNG in conserving sensitive grassland birds.

Changes in grassland bird populations can be associated with modern livestock management methods that reduce variability in vegetation structure, thus reducing suitable

vegetation for both grazing-intolerant and grazing-dependent bird species (Saab et al., 1995). Before European settlement, the interactions of grazing by American bison (*Bison bison*) and prairie dogs (*Cynomys* spp.), fire, and climate, created and maintained patches of different plant communities in the Great Plains resulting in a mosaic of vegetation structure and composition that sustained a diverse grassland bird community (Knopf, 1996; Brennan and Kuvlesky, 2005; Fuhlendorf et al., 2009). These interactions have largely been replaced by management practices emphasizing even distribution of livestock and uniform use (Holechek et al., 1995), creating a more homogenous landscape that favors generalist bird species (Toledo et al., 2014). The decoupling of grasslands from historic disturbances has decreased both temporal and spatial heterogeneity of grasslands (Fuhlendorf and Engle, 2001), and with the suppression of wild fires, grazing has played an increasingly larger role in the structuring of grasslands. Because livestock grazing remains an important economic activity on the LMNG—and has shown to be compatible with wildlife management (Willms and Jefferson, 1993; Brown and McDonald, 1995; Derner et al., 2009)—it is important to further understand the effects of grazing on the structuring of grasslands and breeding populations of sensitive grassland birds.

Bird species' response to management, such as grazing and prescribed burning, have been well documented (Kantrud, 1981; Madden et al., 1999; Owens and Myres, 1973). However, management that may work well in one region may not work in another due to differences in environmental conditions. Therefore it remains difficult to summarize effects of management on individual bird species (Madden et al., 2000). For example, in North Dakota, the Sprague's pipit was most abundant in moderately and heavily grazed areas (Kantrud, 1981), whereas in Alberta, pipits were most abundant in ungrazed or lightly grazed grasslands (Owens and Myres, 1973). Verner and others (1986) proposed using habitat models based on vegetation

attributes instead of summarizing the effects of management on birds. Vegetation attributes are known to determine grassland bird abundance (Wiens, 1973; Whitmore, 1981), and can be easily manipulated by land managers. Land managers can use information on grassland bird habitat preferences to implement management tools (e.g., grazing) that will produce suitable habitat for either a species of concern, or a group of species.

Oil and gas development also has an effect on grassland bird populations (Kalyn Bogard and Davis, 2014; Ludlow et al., 2015; Thompson et al., 2015). In the last decade, western North Dakota has experienced an oil boom in an area that has unusually high grassland bird abundance and diversity (Peterjohn and Sauer, 1999). We hope to provide land managers with more information on the effects of oil extraction on grassland birds in order to minimize the impacts of such development.

2.1.1. Research questions and objectives

There were two main questions in this study. Our first question was “how does livestock grazing affect vegetation structure and composition, sensitive grassland bird abundance, and overall grassland bird diversity on the LMNG?” The second question “how does the rapid expansion of oil and natural gas extraction affect grassland birds on the LMNG?” Three objectives were met to address these questions:

1. Estimated abundance and diversity of grassland birds and vegetation structure and composition in the LMNG (2014-2015).
2. Evaluated how bird abundance and diversity are influenced by vegetation structure and composition (proxies for cattle grazing and stocking rate).
3. Assessed how oil-well and road densities (proxies for oil and natural gas extraction and development) are affecting the grassland bird community on the LMNG.

2.2. Study area

Our study was conducted on the LMNG in western North Dakota, USA (Fig. 1). At 416,334 ha, the LMNG is the largest of the National Grasslands in the United States. The LMNG is divided into two ranger districts, the McKenzie District in the north and the Medora District in the south. Due to the short duration of the breeding season for grassland birds in this region, the large area covered by the LMNG, and limited manpower, we found it was logistically impossible to survey the entire LMNG. Therefore, we focused our sampling efforts in the McKenzie Ranger District in McKenzie County, North Dakota. This also improved our chances of recording Sprague's pipits, which is more common in the northern portion of western North Dakota (Gough et al., 1998). The USFS recognizes two geographic areas within the LMNG: the Badlands Geographic Area and the Rolling Prairie Geographic Area. Our study area was confined to the Rolling Prairie Geographic Area, which encompasses approximately 125,857 ha in the McKenzie District.

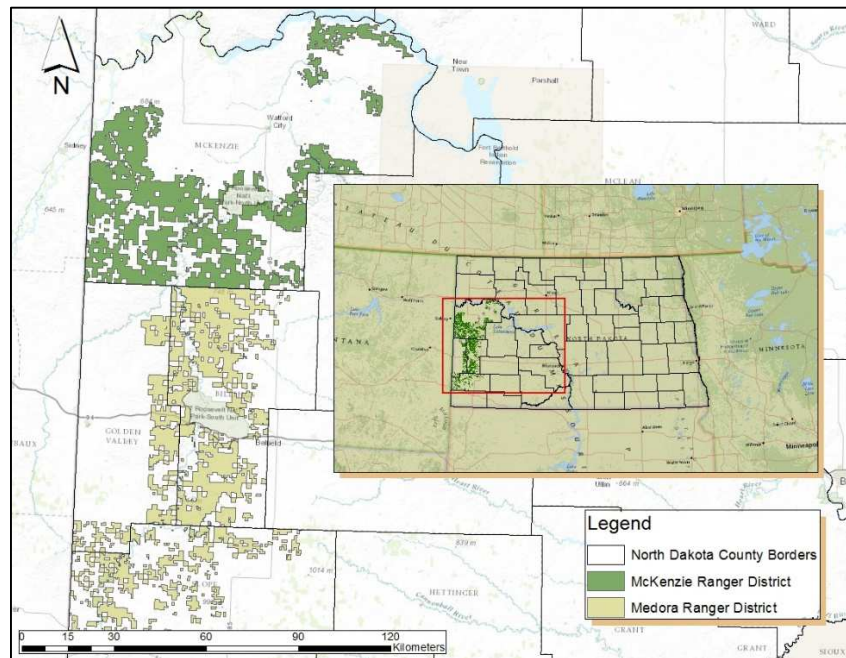


Figure 1. Little Missouri National Grassland located within McKenzie, Golden Valley, Billings, and Slope counties in western North Dakota, USA.

The climate of our study area is a typical continental climate with relatively long, cold winters; short, hot summers; and low rainfall and low humidity (Godfread, 1994). Precipitation can vary greatly among years—averaging 38 to 40 cm—with about three-quarters of that precipitation falling during the growing season that extends approximately from mid-May through mid-September (Godfread, 1994). Nearly level to rolling hills with inclusions of scattered clay buttes, “badland” landscapes, and hardwood draws are characteristic of this region’s topography. The vegetation of the area is typical of mixed-grass prairies in the northern Great Plains with the dominant grasses being blue grama (*Bouteloua gracilis*) and western wheatgrass (*Pascopyron smithii*) (Whitman and Wali, 1975). Some level or nearly level grassland patches that were historically cultivated under the Homestead Act (1862) and subsequently purchased by the U.S. Government under the Bankhead-Jones Farm Tenant Act (1937) are now dominated by crested wheatgrass (Johnson, 1986; Moul, 2006). In general, shorter grasslands are dominated by blue grama and prairie Junegrass (*Koeleria pyramidalata*), whereas taller grasslands are dominated by green needlegrass (*Nassella viridula*) (Whitman and Wali, 1975). There are other non-grassland cover types that occur as intrusions into otherwise fairly continuous grassland. Most of these intrusions are hardwood draws dominated by green ash (*Fraxinus pennsylvanica*), but terraces of silverberry (*Elaeagnus commutata*) and silver sagebrush (*Artemisia cana*) also are present (Godfread, 1994), as well as a few stock ponds and black-tailed prairie dog (*Cynomys ludovicianus*) towns.

2.3. Methods

2.3.1. Study design

We used the legal quarter-section (64.74 ha or 800 × 800 m) as our study site. The quarter-section was chosen for several reasons: 1) boundaries of quarter-sections are generally

well-marked by roads, trails, fence lines, or easily recognized by differences in land-use; 2) the units were small enough so that one or two observers could complete a bird survey in a relatively short period of time (i.e., 1.5 hours per sample unit on average); and 3) duplications in counts of wide-ranging birds are reduced or eliminated. A sample size of 60 sites was chosen on the basis of manpower availability and the estimated time requirements for conducting the field work.

The distribution of our 60 study sites spread randomly throughout the McKenzie District using a stratified design is shown in Figure 2. All sites were located on USFS-owned grasslands.

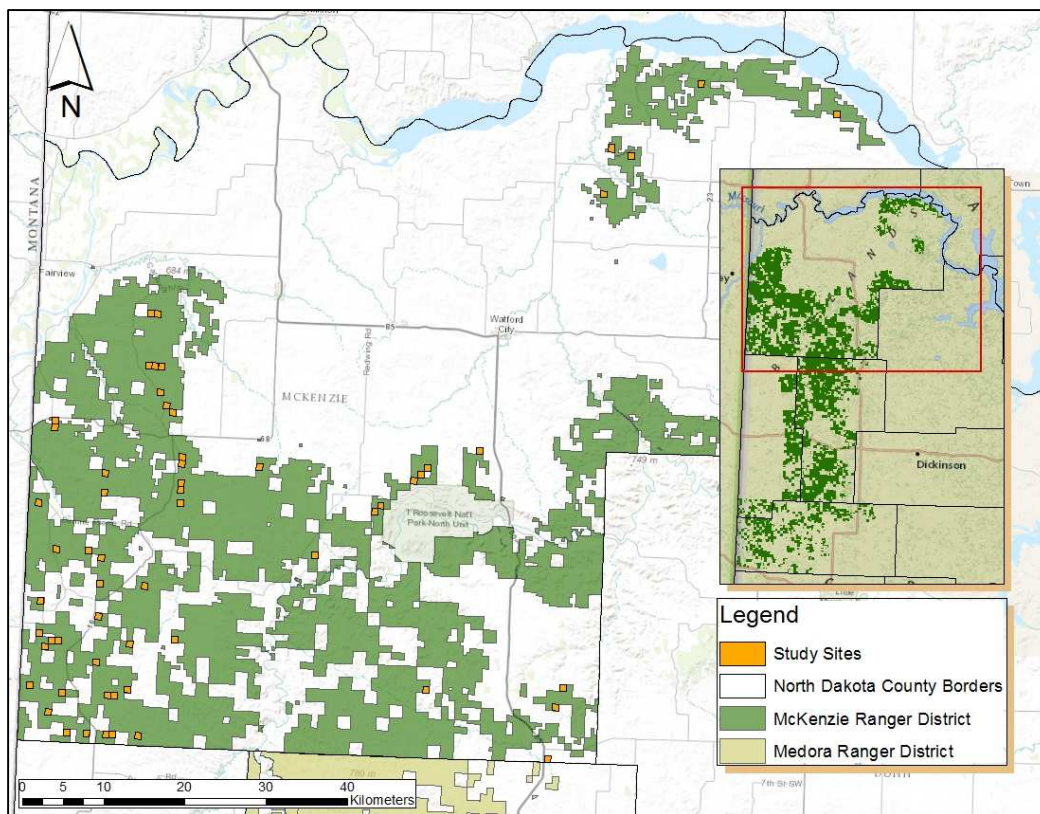


Figure 2. Research sites on the Little Missouri National Grassland in McKenzie, in western North Dakota, USA.

Before selecting our 60 study sites, we first narrowed down the 4,000+ quarter-sections in the McKenzie District to include only quarter-sections that had flat to gently rolling topography (average slope $\leq 15\%$; i.e., the topography preferred by Sprague's pipits according to literature [Government Canada 2011] and expert advice). The average percent slope of each site

was calculated using a digital elevation model (DEM) in ArcGIS (Version 10.2.2; ESRI, Redlands, California). By excluding sites with an average slope greater than 15%, we were able to focus our sampling efforts to areas that Sprague pipits and other grassland birds would use for breeding. We also excluded from consideration all quarter-sections in the McKenzie District that were partially owned by private landowners. We chose our study sites using a stratified randomization design using two covariates that are known to influence Sprague's pipit occurrence and abundance: the density of roads and density of oil wells within a 1.6-km buffer around each quarter-section (Sutter et al., 2000; Ludlow et al., 2015). In this text, we refer to "oil well" or "well" as the contiguous gravel surface that houses all pumping units, storage tanks, natural gas flares, power-lines, and any other associated infrastructure. We did not differentiate between single-bore well pads and multi-bore well pads, and we also included inactive oil wells (≤ 12 months) because the associated infrastructure was still present. To determine road densities, we included all federal, state, county, and USFS gravel or paved roads and associated rights-of-way.

Randomization was achieved by generating a stratified design with 20 unique strata—each strata representing a distinct combination of the two covariates (i.e., 5 levels of well density and 4 levels of road density). The 20 strata ranged from low well and road density to high well and road density. A random list of available study sites was generated for each of the 20 groups. Stratifying in this manner optimizes the range in each covariate so as to maximize habitat suitability modeling (Hirzel and Guison, 2002). We selected the first three quarter-sections in each group unless the quarter-section had a high percentage of woody vegetation, in which case we selected the next quarter-section in the list (Table A1).

Unfortunately, we did not have access to grazing history or stocking rate data for any allotments in the McKenzie District during the study, and thus, could not use grazing or stocking rates as covariates in our study design and site selection. This made it difficult to develop reasonable grazing strata. Although we did not have information on the stocking rates for the individual quarter-sections, the livestock stocking rate recommended by the USFS on all of our study sites ranged from 0.5 to 2.4 stocking hectares (1.3 to 5.9 stocking acres) per animal month (Kyle Dalzell, USFS, personal communication). Pastures selected in this study were managed with several different grazing systems, including early-season crested wheatgrass (*Agropyron cristatum*) use, season long, deferred rotation, twice-over rotation, and 3- to 8-pasture rotations.

2.3.2. Bird census methods

We followed a total-area count (i.e., a modified strip-transect) protocol that was described in Stewart and Kantrud (1972) and Igl and Johnson (1997) to survey all species of breeding birds. Within each sample unit, observers followed systematic transects and were responsible for counting indicated breeding bird pairs within 100 m on either side of the transect line, ensuring coverage of the entire sample unit. We used ArcGIS (10.2.2 ESRI, Redlands, California) to generate a systematic transect route with four separate legs, each measuring 800 m in length (Fig. 3). The first transect leg was spaced 100 m from the study-site edge with subsequent transects spaced 200 m apart. The spacing of the transect route ensures that the entire study area was covered throughout the bird survey.

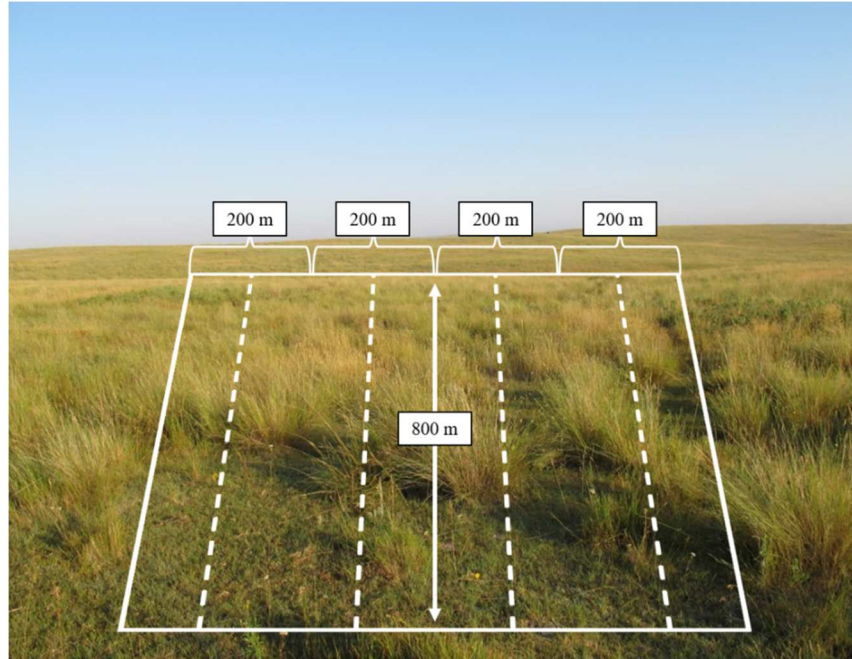


Figure 3. Schematic of site transect routes for breeding bird surveys and sampling vegetation structure in the Little Missouri National Grassland in western North Dakota, 2014 and 2015.

Breeding bird surveys were conducted from late-May to mid-July each year, which coincides with the peak breeding season of breeding birds in this region (Stewart and Kantrud, 1972; Igl and Johnson, 1997). Study sites were surveyed twice each year by one or two observers walking slowly on foot, assuming a walking speed of about 1.0-1.5 km per hr. This rate of progress allows for an observer or observers to efficiently cover a study site in a relatively short period of time, and balanced the length of exposure to individual breeding pairs, which prevents duplication of counts (Igl, 2009). Bibby (2000) indicated that a walking speed of 2 km per hr was reasonable in open habitats.

When two or more random study sites were in close proximity, individual sites were surveyed more efficiently by a single observer. However, when a study site was geographically isolated, it was more efficient to survey the unit using two observers, each covering one-half of the site (i.e., two transects each). On study sites surveyed by two observers, an interval of 400 m between observers was maintained. As this distance is much greater than the distance most

species travel after flushing, there was little chance that an individual bird recorded by one observer would also be recorded by the other (Stewart and Kantrud, 1972). Observers used a DeLorme Earthmate® PN-60 GPS unit to follow transects within each study site. As recommended by Stewart and Kantrud (1972), deviations from the route were allowed and sometimes necessary to adequately survey all portions of the site (e.g., rolling topography) or to track down elusive individuals to confirm identification. Large or wide-ranging birds (e.g., raptors) that flushed from the site upon the observer's arrival or during the survey were recorded as being within the site. In sites that were surveyed by two observers, observers compared field notes at the end of the survey to prevent duplication in the counts.

During the first week of each field season, we trained observers in field protocols and in the identification (aural and visual) of grassland birds. As recommended by Igl (2009), the technicians also were trained to 1) adjust their rate of travel appropriate to the conditions and topography of the quarter-section and to the densities of birds, 2) minimize confusion among individuals or pairs of the same species by observing birds in all directions as the observer moves through the quarter-section and by reconfirming locations of conspecifics as new individuals are encountered along a transect, 3) recognize that some individuals or pairs of some species (e.g., Bobolink [*Dolichonyx oryzivorus*]) might be attracted to or follow an observer and should not be counted more than once (Redmond et al., 1981; Bollinger et al., 1988), and 4) keep track of individuals that move away from an observer, including those that might move from one transect to the next within the same quarter-section (Bibby, 2000). New observers also were accompanied by an experienced observer for several surveys at the beginning of each field season to establish a consistent protocol before proceeding to collect data independently. No

procedures (e.g., call broadcasts or spishing [imitating an alarm call]) were used to entice a bird to sing, call, or alter its behavior to make it more detectable (Igl, 2009).

2.3.3. Breeding bird populations

During the surveys, breeding birds were identified based on aural or visual observations of adults or the presence of an active nest. Surveys of breeding birds were conducted between 0.5 h before sunrise and the midday lull in bird activity, which varies from day to day but usually occurs in the early afternoon in this region (L. D. Igl personal communication; Igl, 2009).

Observers avoided conducting surveys in adverse weather conditions (e.g., heavy precipitation, sustained winds stronger than 24 km per hr), although surveying during light drizzle was allowed if the birds were still active. As recommended by Stewart and Kantrud (1972) and Igl and Johnson (1997), we sometimes used less restrictive standards related to wind speed to provide observers with more time and dates to complete bird surveys.

Counts of birds were based primarily on the number of indicated breeding pairs on territories or home ranges. For most species, nearly all indicated pairs were observed as territorial males or as segregated pairs. In the case of wide-ranging or colonial-nesting species that are not sexually dimorphic (e.g., raptors, grouse, shorebirds, swallows), one or two individuals were considered to represent a pair, but if more than two individuals were observed on a study site, the total number of indicated pairs was derived by halving the total number of individual counts and rounding up to the nearest whole pair. We based the number of indicated pairs of brown-headed cowbird (*Molothrus ater*) on the total number of females. Birds flying overhead were only counted if they were actually using the field, such as flycatching, courtship or communal displaying, or hunting. Any pair or lone singing male that occurred on a field

border or fence was counted as half a pair, based on the assumption that field edges divide the average edge territory into two equal parts (Verner, 1986).

We did not consider certain birds observed during the surveys to be using our study sites and excluded them from our results (Igl and Johnson, 1997; Igl, 2009). These included (1) migrant flocks; (2) wide-ranging colonial waterbirds (e.g., pelicans, cormorants, egrets, herons) passing high overhead; and (3) other birds passing overhead in high, direct flight. Juveniles were recorded but were not considered part of the breeding population at a site; however, a single adult or a pair of adults accompanied by one or more juveniles was counted as a single pair. Vernacular and scientific names follow the checklist of the American Ornithologists' Union (Chesser et al., 2015).

2.3.4. Vegetation sampling

Fisher and Davis (2010) reviewed literature on grassland bird habitat selection and identified 118 vegetation variables that researchers have found to be important in habitat selection by grassland birds. Of those 118 vegetation variables, nine variables appeared to be consistent predictors of grassland bird habitat use: coverage of bare ground, grass, dead vegetation, forbs, and litter; an index of vegetation density; vegetation volume; litter depth; and vegetation height. Of those nine variables, bare-ground exposure, vegetation height, and litter depth were three of the most consistent predictors of habitat use by grassland birds (Fisher and Davis, 2010). In this study, we measured all nine vegetation variables that Fisher and Davis (2010) found to be important predictors of grassland bird habitat use to reduce the number of a priori hypotheses and to ultimately provide land managers with useful decision-support tools to manage habitat for grassland birds. In addition, we also included measures of floristic composition because the literature suggested that some species of concern, including the

Sprague's pipit and Baird's sparrow, select native vegetation over non-native vegetation in grasslands (Wilson and Belcher, 1989; Madden et al., 2000).

2.3.4.1. Structural vegetation sampling

To characterize vegetation structure (e.g., visual obstruction, vegetation height, litter depth) in each quarter-section at the time of the bird surveys, we collected structural data on or near (i.e., within 3 days) the date of each bird survey. Twenty sampling stations were placed systematically along each of the four 800-m birding transect legs at 41-m intervals—80 stations per site—to get a good representation of the entire study site. Visual obstruction readings (VOR) were taken using a modified Robel pole (Robel et al., 1970; Benkobi et al., 2000). The 1-m Robel pole was marked with alternating 2.5-cm bands and numbered beginning with one at the base of the pole. A metal spike was attached to the bottom of the pole and was pushed into the ground until the bottom of the pole came into contact with the ground. The observer moved 4 m away from the pole, and then with eyes 1 m above ground level, recorded the lowest interval on the pole that was not completely obscured by vegetation (Fig. 4). A meter stick was attached to the Robel pole by a 4-m string to maintain a consistent observation distance and height. For example, if the third VOR band was visible, the VOR was recorded as 3 (i.e., 7.5 cm). At each station, two VOR measurements were recorded at opposite cardinal directions and then averaged for each point. Maximum vegetation height (cm) and litter depth (cm) also were measured at each station using a meter stick. Observers measured the height, in cm, of the highest piece of vegetation within 15 cm of the Robel pole using a meter stick. We considered litter to be any horizontal, unconsolidated plant material not anchored to the ground.

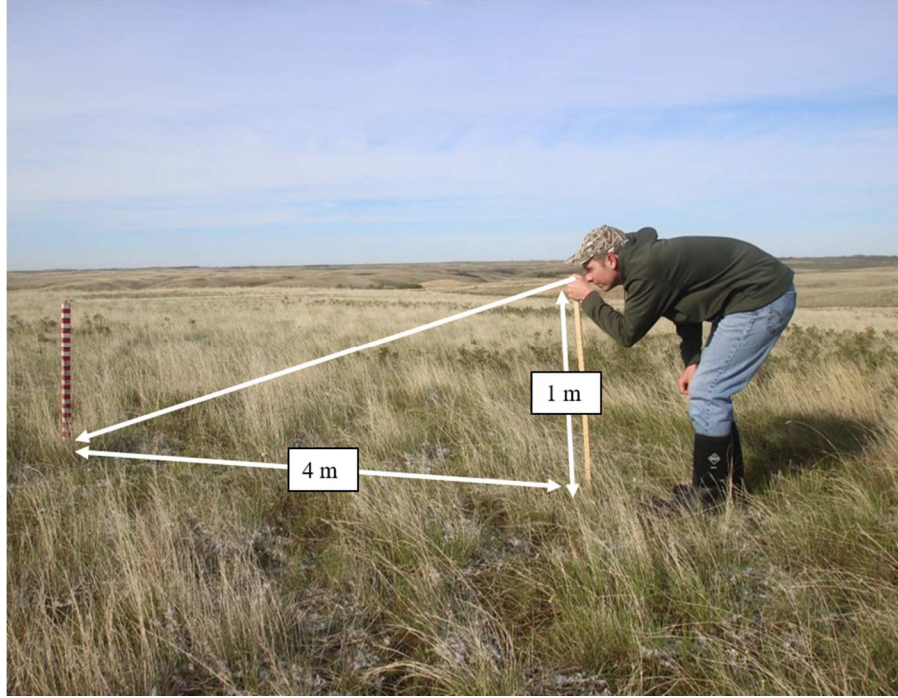


Figure 4. Observer recording visual obstruction reading using a Robel pole in the Little Missouri National Grassland in western North Dakota.

Herbage standing crop also was sampled in 2014 as a proxy for vegetation volume. Standing crop was measured directly by clipping herbage from 0.25-m² quadrats placed systematically along each transect at every fourth sampling station, for a total of 20 clippings per study site. Our sampling density for biomass is similar to that recommended by Uresk and Benzion (2007), who suggested a minimum of three transects with 20 stations per transect for monitoring areas ≤ 259 ha (i.e., legal section). Vegetation in each quadrat was clipped to ground level from the sampling station's center after other structural measurements were recorded. Vegetation samples were bagged, oven-dried for 48 hr at 110 °C, and then weighed.

2.3.4.2. *Vegetation composition*

Several researchers have found that some grassland bird species—Sprague's pipit and Baird's sparrow in particular—are significantly more abundant in native prairies than non-native grasslands (Wilson and Belcher, 1989; Dale, 1992; Anstey et al., 1995; Madden, 1996). To

assess this assertion, we characterized the vegetation species composition of 57 study sites using a modified Whittaker plot (Stohlgren et al., 1995; fig. 5). We did not survey three of our study sites due to logistical constraints. Given that species composition does not vary appreciably from one year to the next in grasslands (Gibson and Hulbert, 1987; Tilman and Downing, 1994; DeKeyser et al., 2015), floristic composition was measured only once in the two field seasons, one-half of the study sites in the first year and one-half during the second year. Three 1,000-m² Whittaker plots were sampled in each quarter-section. Each Whittaker plot measures 20 × 50 m (1,000 m²) and contained nested subplots of three different sizes. A 5 × 20-m (100-m²) subplot was placed in the plot's center, and two 2 × 5-m (10-m²) subplots were placed in opposite corners of the plot. Presence/absence data were collected for the 10-m², 100-m², and 1,000-m² subplots. There also was a total of ten 0.5-m × 2-m (1-m²) "microplots". Six of the microplots were arranged systematically inside and adjacent to the 1,000-m² plot perimeter, and the other four were arranged systematically outside and adjacent to the 100-m² subplot perimeter. Percent cover of all species and substrate variables (e.g., bare ground, litter) was visually estimated to the nearest 1% within the microplots. Species that did not comprise 1% of the microplot were given a value of 0.1%. Using ArcGIS (10.2.2 ESRI, Redlands, California), we placed ten randomized points at each site to be used as the starting point for each plot. Using their best judgment, observers would choose three points that were spatially widespread, did not fall within non-grassland features (e.g., woody draws), and gave a good representation of the entire quarter-section's vegetation composition within grasslands. Once on the point, a random number generator was used to obtain a directional bearing on which the plot would be oriented.

vegetation variables (i.e., VOR, maximum height, litter depth, and biomass) were averaged for each study site by year between the two survey periods. Density of oil wells, length of roads (km), and percentage of grassland within a 1.6 km buffer of the quarter-section were used to assess the level of disturbance in the surrounding landscape (i.e., landscape-level models). To calculate oil-well densities, we only included the following well statuses as described by the North Dakota Oil and Gas Commission (2016): active, drilling, inactive (≤ 12 months), not completed, and temporarily abandoned. Percent coverages of bare ground, litter, Kentucky bluegrass (*Poa pratensis*), and crested wheatgrass were calculated as an average of all cover estimates from the Whittaker microplots. We included percent coverage of Kentucky bluegrass and crested wheatgrass in our final analyses because literature suggested that these variables influence sensitive grassland bird presence or abundance (Wilson and Belcher, 1989).

We also calculated a Floristic Quality Index (FQI) (NGPFQAP, 2001) for each site using plant presence/absence data collected using the Whittaker subplots. Floristic quality assessments assign a rating to each plant species that reflects the fundamental conservatism that the species exhibits for natural habitats. We used a list of coefficients of conservatism (C values) developed for the Dakotas by the Northern Great Plains Floristic Quality Assessment Panel (2001). C values represent a plant species' pattern of occurrence (i.e., common or rare) and if it is natural-area dependent. C values range from 0-10. Ubiquitous species are given a low C value, and species that exhibit specific adaptations are given a higher C value. The FQI is obtained by multiplying mean C by the square root of the number of native species present. Thus, the FQI is a weighted species-richness estimate that uses a square root transformation of the number of native species present to limit the influence of area alone on species richness (Swink, 1974). We

calculated FQI using the Universal Floristic Quality Assessment Calculator (Freyman et al., 2015).

Other researchers have detected a strong relationship between VOR and standing crop (Robel et al., 1970; Vermeire and Gillen, 2001; Woehl, 2010). Based on the recommendation of Vermeire and Gillen (2001), we ran a regression at the site level to explore the relationship between standing crop and VOR. Regression models based on the site—rather than individual observations—account for less variation because the true area measured by VOR is unknown, 3-dimensional, and may vary among points; whereas quadrat size is 2-dimensional and consistent among points. Models developed at the site level reduce this source of error by averaging both VOR and standing crop over many individual points (Vermeire and Gillen, 2001). Mean standing crop was calculated for the second year of the study by entering mean VOR's into the regression model. Definitions of all explanatory variables can be found in Table 1.

Table 1. Covariate abbreviations and corresponding descriptions for landscape and site-specific variables recorded at study sites in the Little Missouri National Grassland in western North Dakota, 2014 and 2015.

Variable type	Covariate abbreviation.	Description
Landscape	Percent.Grass	Percentage grassland (e.g., range, hayland) within 1.6 km of site boundary.
	Wells	Well density (number of wells) within 1.6 km of site boundary.
	Roads	Total road length (km) within 1.6 km of site boundary.
Site-specific	Ltr.Depth	Litter depth (cm).
	Height	Maximum vegetation height (cm) within 15 cm of Robel pole.
	AvVOR	Average visual obstruction reading (cm).
	kgha	Standing crop or biomass (kg per ha).
	Percent.AGCI	Percentage cover of crested wheatgrass.
	Percent.POPR	Percentage cover of Kentucky bluegrass.
	Percent.BG	Percentage cover of bare ground.
	Percent.Litter	Percentage cover of litter.
	FQI	Floristic Quality Index.
	Slope	Average percent slope of quarter-section.

We selected a suite of 12 grassland bird species to evaluate the effects of landscape and site-specific variables on breeding bird densities: sharp-tailed grouse (*Tympanuchus phasianellus*), upland sandpiper (*Bartramia longicauda*), horned lark (*Eremophila alpestris*), Sprague's pipit, clay-colored sparrow (*Spizella pallida*), field sparrow (*Spizella pusilla*), vesper sparrow (*Pooecetes gramineus*), grasshopper sparrow (*Ammodramus savannarum*), Baird's sparrow, chestnut-collared longspur (*Calcarius ornatus*), bobolink, and western meadowlark (*Sturnella neglecta*). We used an information-theoretic approach (Burnham and Anderson, 2002) to model individual bird species' abundances against landscape factors (i.e., percent grassland, length of roads, and oil well density, all within 1.6 km of the border of the quarter-section) and site-specific factors (i.e., slope, VOR, maximum height, litter depth, and percentage cover of bare ground, litter, Kentucky bluegrass, and crested wheatgrass). Models were formulated as general linear models (GLMs) with an assumed Gaussian distribution based on an $\ln(y + 1)$ transformation. We ranked models using Akaike's Information Criteria (AIC) corrected for small sample size (AIC_c) by computing the difference (Δ_i) between the model with the smallest AIC_c and the model with the next smallest AIC_c (Burnham and Anderson, 2002). In general, models with $\Delta_i \leq 2$ have substantial support, those with Δ_i of 4-7 have considerably less support, and those with $\Delta_i > 10$ have essentially no support (Burnham and Anderson, 2002). Because AIC_c is a relative measure, Burnham and Anderson (1998) recommended calculating the AIC differences—or delta AIC ($\Delta_i = AIC_{c,i} - \min AIC_c$)—for each candidate model. The best model has a $\Delta_i = 0$. Akaike weights (ω_i)—relative likelihood of a model—are also reported. The relative importance of each model was assessed by computing Akaike's model weights (ω_i) and

we used root-mean-squared errors (RMSE) and adjusted R^2 (Adj. R^2) to assess the goodness-of-fit of the final model(s).

Because we had limited information on which predictors might be useful a priori, we took a two-step approach for deriving potential plausible models. Following habitat selection as advocated by Johnson (1980), in the first stage, we looked at higher-level selection by examining which of three landscape predictors might explain abundance of bird species using a suite of eleven plausible models (Table 2). Year was included in all candidate models (except the null model), regardless of its importance, because grassland bird populations in this region are known to exhibit considerable annual variability in abundance from year-to-year on any particular site (Igl and Johnson, 1997, 1999; Igl et al., 2008). In the second stage, uncorrelated site-specific variables were then added to the best model from the landscape models to see if they improved the model fit (Table 3). Overall, 25 site-specific plausible models were considered. Because bird abundance and covariates, particularly site, can vary widely from year-to-year on each of the sites, we assumed independence. To account for variation in the strength of relationships between years, we included interaction terms between year and potential landscape and/or site-specific variables. Bivariate plots by year were used as a descriptive method to better understand the strength and direction of any relationships between bird abundance and covariates deemed useful from the modeling effort. All statistical analyses were conducted in Program R (version 3.2.3; R Core Team 2015). The following R packages were used: “AICcmodavg” (Mazerolle, 2016), “MuMIn” (Barton, 2016), and “vegan” (Oksanen et al., 2016).

We also used the aforementioned GLM modeling selection to assess the effects of explanatory variables on overall grassland bird diversity by calculating Shannon Diversity (H) and using it as the dependent variable in the models. We restricted our analysis to the 12 most

common grassland birds detected on our sites. This approach allowed for simple interpretation of the effects of the 13 explanatory variables on grassland bird diversity.

Table 2. Plausible models using landscape-level variables including well density (Wells), total length of roads (Roads), and percentage grass within 1.6 km of quarter-section edge (Percent.Grass). Refer to Table 1 for covariate descriptions.

Model No.	Model description
1	Null
2	Year
3	Year + Wells
4	Year + Wells + Year×Wells
5	Year + Roads
6	Year + Roads + Year×Roads
7	Year + Percent.Grass
8	Year + Percent.Grass + Year×Percent.Grass
9	Year + Year×Percent.Grass + Year×Wells
10	Year + Year×Percent.Grass + Year×Roads
11	Year + Year×Roads + Year×Wells

Table 3. Plausible models using site-specific variables including average visual obstruction reading (AvVOR), percent slope (Slope), Native Floristic Quality Index (Native.FQI), and percentage cover of crested wheatgrass (Percent.AGCR), Kentucky bluegrass (Percent.POPR), bare ground (Percent.BG), and litter (Percent.Litter). Refer to Table 1 for covariate descriptions.

Model No.	Model description
12	Best + AvVOR
13	Best + AvVOR + Year×AvVOR
14	Best + Slope
15	Best + Slope + Year×Slope
16	Best + FQI
17	Best + FQI + Year×FQI
18	Best + Percent.AGCR
19	Best + Percent.AGCR + Year×Percent.AGCR
20	Best + Percent.POPR
21	Best + Percent.POPR + Year×Percent.POPR
22	Best + Percent.BG
23	Best + Percent.BG + Year×Percent.BG
24	Best + Percent.Litter
25	Best + Percent.Litter + Year×Percent.Litter
26	Best + Ltr.Depth
27	Best + Ltr.Depth + Year×Ltr.Depth

2.4. Results

2.4.1. General

Average herbaceous standing crop among sites ranged from 846 to 2406 kg per ha. We used the slope and intercept of the regression model to calculate standing crop estimates for 2015 (Fig. 6).

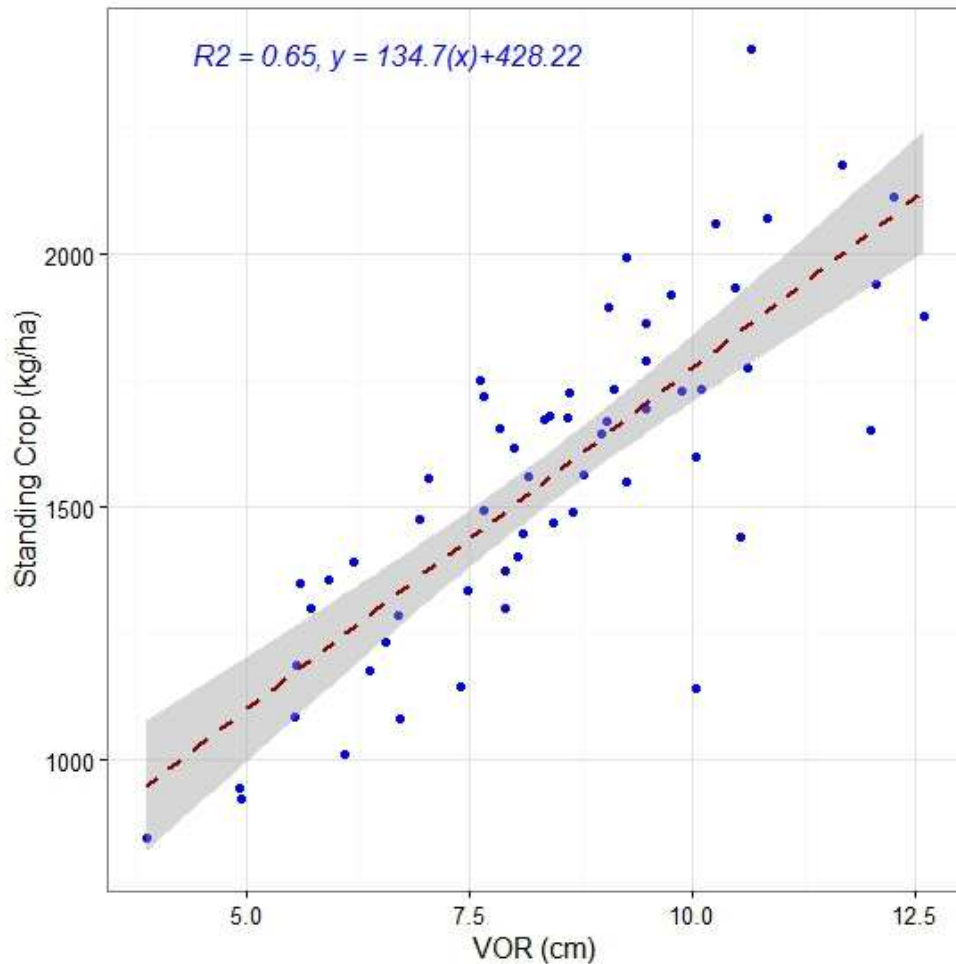


Figure 6. Linear regression plot between mean standing crop (biomass) and mean visual obstruction readings (VOR) with 95% confidence intervals for 60 quarter-section sites in the Little Missouri National Grassland, 2014 and 2015.

Patterns of correlation among the 13 explanatory variables were explored by calculating Pearson's correlation coefficients. The following explanatory variables were found to be correlated ($r \geq 40\%$) (Table 4): VOR, maximum vegetation height, and biomass; FQI and percent

cover of crested wheatgrass; and percent bare ground and percent litter cover. Accordingly, we did not include any of the correlated variables within the same plausible models. VOR was used in place of vegetation height and biomass in the models because height and biomass were highly correlated with VOR ($r \geq 70\%$). Summary statistics for the 13 explanatory variables can be found in Table 4.

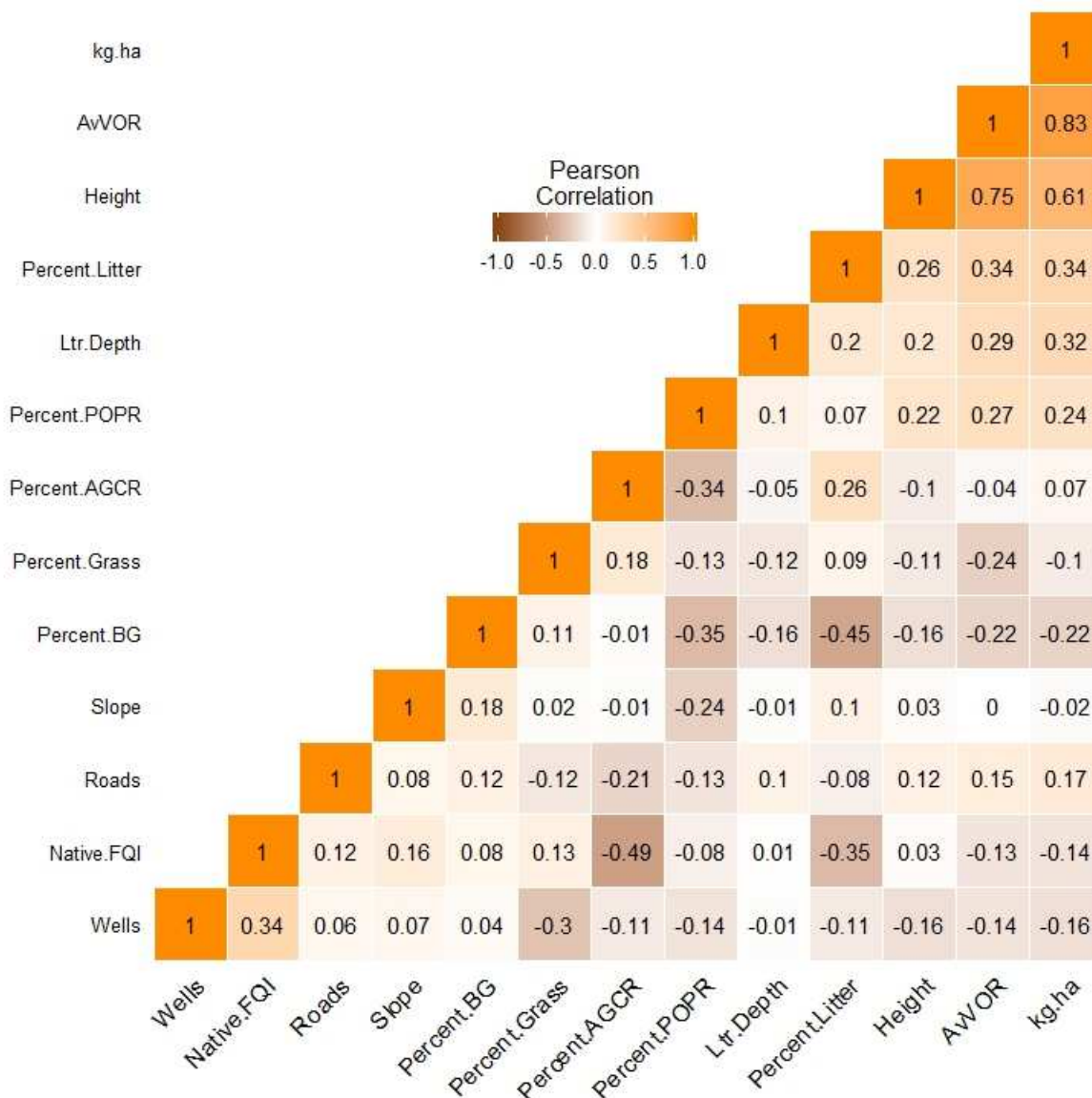


Figure 7. Correlation heatmap with Pearson correlation coefficients for landscape and site-specific covariates ($n = 57$). Positive correlations are displayed in orange and negative correlations are in brown. Color intensity is proportional to the correlation.

Table 4. Summary statistics for 13 explanatory variables collected on 57 sites on the Little Missouri National Grassland in western North Dakota from late-May through mid-August 2014, and 2015.

Variable	2014			2015		
	Range	\bar{x}	SD	Range	\bar{x}	SD
Landscape variables:						
Percent.Grass	33.6-97.4	77.1	12.9	33.6-97.4	77.1	12.9
Wells	0.0-17.0	2.0	3.5	0.00-17.00	2.0	3.5
Roads	0.0-18.8	12.1	4.1	0.00-18.80	12.1	4.1
Site-specific variables:						
Ltr.Depth (cm)	0.54-3.24	1.8	0.6	1.9-5.0	3.6	0.8
Height (cm)	22.8-57.1	44.2	7.5	27.9-59.8	41.6	5.7
AvVOR (cm)	4.4-13.2	8.8	2.1	4.3-11.9	7.8	1.8
kg.ha	1019.6-2202.5	1613.9	288.0	1004.9-2023.6	1477.8	245.6
Percent..AGCR	0-25.9	4.9	7.0	0-25.9	4.9	7.0
Percent.POPR	0-20.4	5.9	5.7	0-20.4	5.9	5.7
Percent.BG	0.2-40.5	7.8	8.0	0.2-40.5	7.8	8.0
Percent.Litter	10.8-72.9	46.2	11.8	10.8-72.9	46.2	11.8
FQI	23.4-52.2	39.2	6.7	23.4-52.2	39.2	6.7
Slope	2.6-14.9	9.4	2.6	2.6-14.9	9.4	2.6

During the breeding seasons of 2014 and 2015, we detected 69 and 76 bird species, respectively. We observed 7,789 breeding pairs representing 82 bird species over the course of the study (Table A2). The most frequently observed species were the grasshopper sparrow and western meadowlark, which were detected on 100% of the study sites, vesper sparrow (97%), and mourning dove (*Zenaida macroura* [88%]). The 20 most frequently observed species are summarized in Table 5. The suite of 12 grassland birds selected for further analyses all occurred on >20% of the study sites. Sensitive species detected in USFS Region 1 over the duration of this monitoring program include: burrowing owl (*Athene cunicularia*), loggerhead shrike (*Lanius ludovicianus*), Sprague's pipit and Baird's sparrow. Other birds we observed that are considered sensitive by the USFS were burrowing owl (*Athene cunicularia*) and loggerhead shrike (*Lanius ludovicianus*). We also observed two breeding pairs of long-billed curlew (*Numenius americanus*) near one of our study sites during both years of the study; however, they were never observed using any of the study sites during our breeding bird surveys.

We recorded 195 plant species in 171 modified Whittaker plots on 57 study sites in 2014 and 2015 (Table A3). Native species accounted for 86.7% (169 species) of the total plant community, whereas non-native species accounted for 13.3% (26 species) of the total plant community. The average Native Mean C value for the study area is 5.1 and the average FQI is 39.2. Forbs comprised 65.6% of the plant community; grasses and sedges combined for 20.5% of the plant community; shrubs and trees accounted for 11.8% of the plant community; and ferns, bryophytes, and vines, combined for 2% of the plant community. FQI for individual sites ranged from 23.4 to 52.2 (Table A4). The five vegetation composition variables with the highest percent cover (averaged across all sites) were: litter (46.4%), bare ground (7.8%), western wheatgrass (5.9%), Kentucky bluegrass (5.9%), and crested wheatgrass (4.7%)

Table 5. Summary statistics for the 20 most frequently observed breeding bird species during surveys conducted on the Little Missouri National Grassland in western North Dakota between 23 May to 25 July 2014 and 19 May to 17 July 2015. The species are ordered by frequency of occurrence.

Species	Sites observed ¹	Frequency occurrence	Average densities (no. pairs per 100 ha)	Density SD	Density range
Grasshopper sparrow	119	1.00	30.92	12.8	3.9-65.0
Western meadowlark	119	1.00	22.53	8.1	0.8-38.0
Vesper sparrow	116	0.97	6.80	4.4	0.0-22.8
Mourning Dove	108	0.88	2.28	1.8	0.0-7.9
Eastern kingbird	100	0.82	2.18	1.8	0.0-7.7
Bobolink	95	0.77	4.22	4.2	0.0-17.0
Brown-headed cowbird	92	0.75	1.83	1.9	0.0-9.3
Clay-colored sparrow	91	0.74	3.32	5.0	0.0-28.3
Sharp-tailed grouse	89	0.72	1.70	2.0	0.0-11.6
Yellow warbler	88	0.71	2.54	2.6	0.0-14.0
Spotted towhee	81	0.66	2.34	2.9	0.0-14.8
Field sparrow	79	0.64	2.27	2.7	0.0-14.8
Upland sandpiper	75	0.61	1.23	1.3	0.0-4.7
Brown thrasher	65	0.52	0.79	1.0	0.0-3.8
Horned lark	58	0.46	1.85	3.5	0.0-18.9
House wren	52	0.41	0.98	1.6	0.0-7.0
Red-winged blackbird	47	0.37	0.94	2.2	0.0-14.3
Sprague's pipit	44	0.34	1.61	3.1	0.0-13.2
Baird's sparrow	40	0.31	1.31	2.8	0.0-13.9
Chestnut-collared longspur	32	0.24	1.66	4.9	0.0-33.2

¹ n = 60 site-by-year combination.

2.4.2. Modeling results

2.4.2.1. Grassland bird community

The best supported and most parsimonious landscape model for grassland bird diversity had weak evidence ($\omega_i = 0.38$, $R^2 = 0.06$) that diversity is associated with Percent.Grass (Table 6). One site-specific variable (VOR) improved the best-supported landscape model ($\omega_i = 0.51$), and explained 12% of the variation in grassland bird diversity. The best-supported site-specific model did not include any Year interactions, therefore the relationship between grassland bird diversity and the explanatory variables did not vary from year-to-year. Grassland bird diversity showed a slight decline with increasing percentage cover of grassland within 1.6 km of the site edge and average VOR (Fig. 8).

2.4.2.2. Sharp-tailed grouse

The best supported and most parsimonious landscape model for the sharp-tailed grouse included Year and Wells (Table 7). However, the evidence that sharp-tailed grouse abundance is a function of Year and Wells is weak ($\omega_i = 0.23$, $R^2 = 0.03$). One site-specific variable (Ltr.Depth) improved the best-supported landscape model relative to other models ($\omega_i = 0.39$), but only explained 7% of the variation in sharp-tailed grouse abundance. The best site-specific model did not include any Year interactions, thus the relationship between sharp-tailed grouse abundance and Ltr.Depth did not vary substantially from year-to-year. Although many sites had zero sharp-tailed grouse across the range of Wells and Ltr.Depth, sharp-tailed grouse abundance declined with increasing well density (Fig. 9). Sharp-tailed grouse abundance slightly increased with increasing litter depth in 2014 and 2015.

Table 6. Model-selection results for models relating grassland bird diversity (Shannon $[H]$) to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC_c). Variable definitions are given in Table 1.

Model		K ¹	AIC _c	Δ_i ²	ω_i ³	RMSE ⁴	Adj. R ²
Landscape models:							
mod7	Year + Percent.Grass	4	-307.2	0.0	0.38344	0.06062	0.06
mod8	Year + Percent.Grass + Year * Percent.Grass	5	-305.3	2.0	0.14438	0.06056	0.05
mod10	Year + Year * Percent.Grass + Year * Roads	7	-305.1	2.2	0.12933	0.05943	0.07
mod5	Year + Roads	4	-304	3.3	0.07446	0.06150	0.03
mod9	Year + Year * Percent.Grass + Year * Wells	7	-303.8	3.4	0.06966	0.05975	0.06
mod2	Year	3	-303.3	4.0	0.05233	0.06227	0.02
mod4	Year + Wells + Year * Wells	5	-302.8	4.4	0.04169	0.06122	0.03
mod1	Null	2	-302.3	5.0	0.03195	0.06312	0.0
mod3	Year + Wells	4	-301.9	5.3	0.02646	0.06206	0.02
mod6	Year + Roads + Year * Roads	5	-301.8	5.5	0.02493	0.06150	0.02
mod11	Year + Year * Roads + Year * Wells	7	-301.5	5.8	0.02138	0.06037	0.04
Best landscape model plus site-specific models:							
mod12	Year + Percent.Grass + AvVOR	5	-313.2	0.0	0.50792	0.05850	0.12
mod13	Year + Percent.Grass + AvVOR + Year * AvVOR	6	-311	2.2	0.17025	0.05849	0.11
mod24	Year + Percent.Grass + Percent.Litter	5	-309.1	4.1	0.06557	0.05956	0.09
mod17	Year + Percent.Grass + Native.FQI + Year * Native.FQI	6	-308.9	4.3	0.05973	0.05903	0.09
mod16	Year + Percent.Grass + Native.FQI	5	-308.2	4.9	0.04305	0.05978	0.08
mod26	Year + Percent.Grass + Ltr.Depth	5	-307.8	5.4	0.03479	0.05989	0.08
mod7	Year + Percent.Grass	4	-307.2	5.9	0.02636	0.06062	0.06
mod25	Year + Percent.Grass + Percent.Litter + Year * Percent.Litter	6	-307.1	6.1	0.02435	0.05950	0.08
mod27	Year + Percent.Grass + Ltr.Depth + Year * Ltr.Depth	6	-305.6	7.5	0.01177	0.05988	0.07
mod18	Year + Percent.Grass + Percent.AGCR	5	-305.5	7.6	0.01123	0.06049	0.06
mod22	Year + Percent.Grass + Percent.BG	5	-305.3	7.8	0.01008	0.06055	0.05
mod14	Year + Percent.Grass + Slope	5	-305.3	7.9	0.00983	0.06056	0.05
mod20	Year + Percent.Grass + Percent.POPR	5	-305.1	8.1	0.00900	0.06061	0.05
mod23	Year + Percent.Grass + Percent.BG + Year * Percent.BG	6	-303.9	9.3	0.00487	0.06034	0.05
mod19	Year + Percent.Grass + Percent.AGCR + Year * Percent.AGCR	6	-303.8	9.4	0.00464	0.06037	0.05
mod15	Year + Percent.Grass + Slope + Year * Slope	6	-303.3	9.9	0.00359	0.06050	0.05
mod21	Year + Percent.Grass + Percent.POPR + Year * Percent.POPR	6	-302.9	10.3	0.00296	0.06061	0.04

¹ Number of parameters.

² Delta AIC (measure of each model relative to the best model).

³ Akaike weights (measure of the strength of evidence for each model).

⁴ Root mean square error.

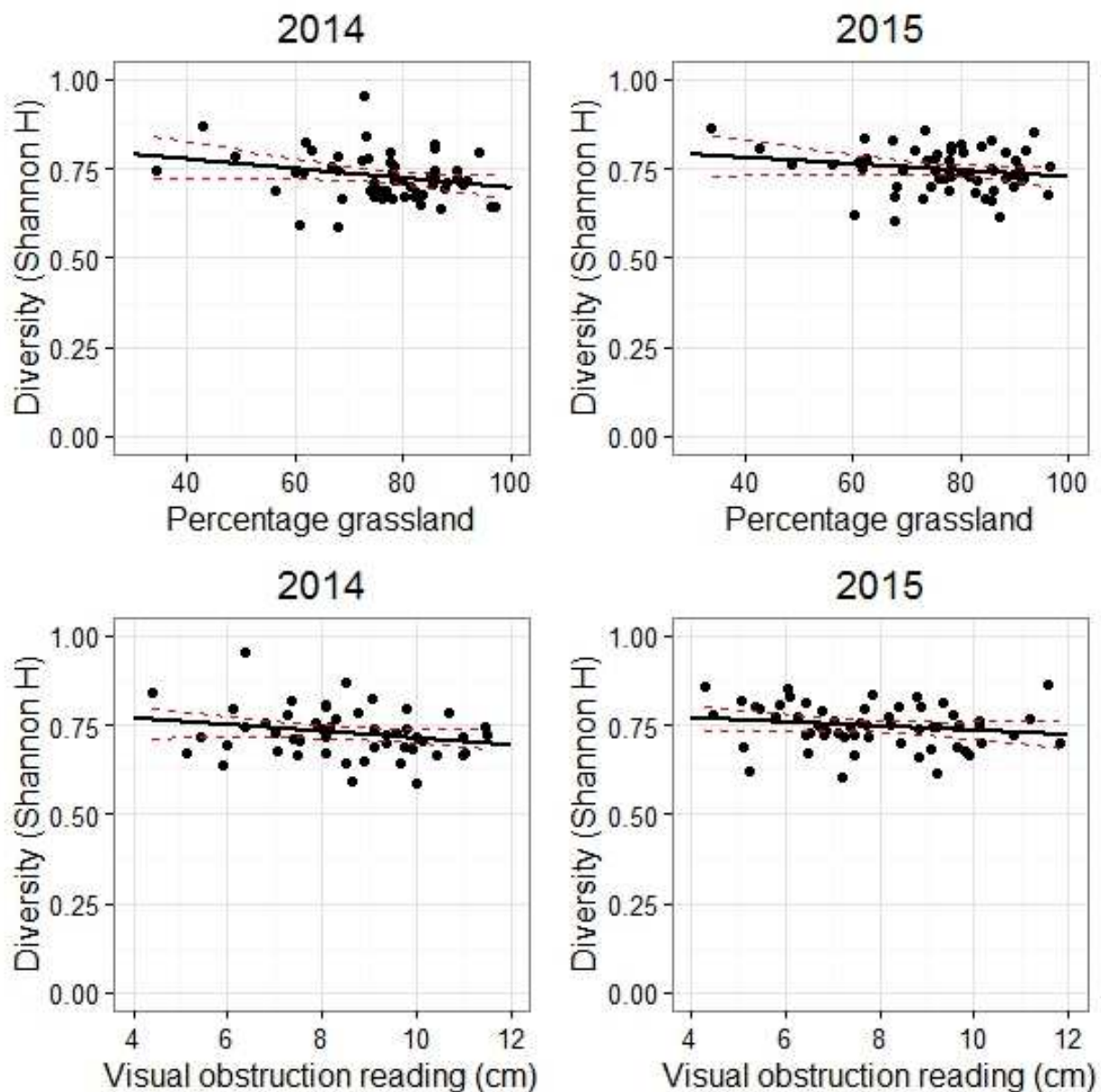


Figure 8. Model results showing relationship (black line with red-dashed 95% confidence intervals) between grassland bird diversity (Shannon [H']) and percentage grassland and visual obstruction reading (cm).

Table 7. Model-selection results for models relating sharp-tailed grouse abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC_c). Variable definitions are given in Table 1.

Model		K ¹	AIC _c	Δ_i ²	ω_i ³	RMSE ⁴	Adj. R ²
Landscape models:							
mod3	Year + Wells	4	223.6	0.0	0.23247	0.62191	0.03
mod7	Year + Percent.Grass	4	224.2	0.6	0.17222	0.62355	0.02
mod2	Year	3	224.3	0.7	0.16065	0.62983	0.01
mod1	Null	2	224.6	1.0	0.14256	0.63636	0.00
mod4	Year + Wells + Year * Wells	5	225.6	2.0	0.08497	0.62143	0.02
mod8	Year + Percent.Grass + Year * Percent.Grass	5	225.6	2.0	0.08485	0.62144	0.02
mod5	Year + Roads	4	226.4	2.8	0.05639	0.62968	0.00
mod9	Year + Year * Percent.Grass + Year * Wells	7	227.8	4.3	0.02768	0.61530	0.02
mod6	Year + Roads + Year * Roads	5	228.6	5.0	0.01889	0.62968	-0.01
mod10	Year + Year * Percent.Grass + Year * Roads	7	229.9	6.3	0.00983	0.62092	0.00
mod11	Year + Year * Roads + Year * Wells	7	230.0	6.4	0.00948	0.62111	0.00
Best landscape model plus site-specific models:							
mod26	Year + Wells + Ltr.Depth	5	219.6	0.0	0.38544	0.60523	0.07
mod27	Year + Wells + Ltr.Depth + Year * Ltr.Depth	6	221.5	1.9	0.15038	0.60431	0.07
mod16	Year + Wells + FQI	5	222.4	2.8	0.09576	0.61267	0.05
mod3	Year + Wells	4	223.6	4.0	0.05192	0.62191	0.03
mod21	Year + Wells + Percent.POPR + Year * Percent.POPR	6	223.7	4.1	0.04967	0.61021	0.05
mod12	Year + Wells + AvVOR	5	223.7	4.2	0.04814	0.61637	0.04
mod24	Year + Wells + Percent.Litter	5	223.9	4.3	0.04422	0.61683	0.03
mod17	Year + Wells + FQI + Year * FQI	6	224.3	4.7	0.03614	0.61191	0.04
mod20	Year + Wells + Percent.POPR	5	225.4	5.8	0.02108	0.62085	0.02
mod14	Year + Wells + Slope	5	225.5	5.9	0.01988	0.62117	0.02
mod18	Year + Wells + Percent.AGCR	5	225.7	6.2	0.01778	0.62178	0.02
mod22	Year + Wells + Percent.BG	5	225.8	6.2	0.01738	0.62191	0.02
mod19	Year + Wells + Percent.AGCR + Year * Percent.AGCR	6	225.9	6.3	0.01640	0.61617	0.03
mod13	Year + Wells + AvVOR + Year * AvVOR	6	225.9	6.3	0.01619	0.61624	0.03
mod25	Year + Wells + Percent.Litter + Year * Percent.Litter	6	226.1	6.5	0.01476	0.61674	0.03
mod23	Year + Wells + Percent.BG + Year * Percent.BG	6	227.3	7.7	0.00833	0.61984	0.02
mod15	Year + Wells + Slope + Year * Slope	6	227.7	8.2	0.00653	0.62117	0.01

¹ Number of parameters.

² Delta AIC (measure of each model relative to the best model).

³ Akaike weights (measure of the strength of evidence for each model).

⁴ Root mean square error.

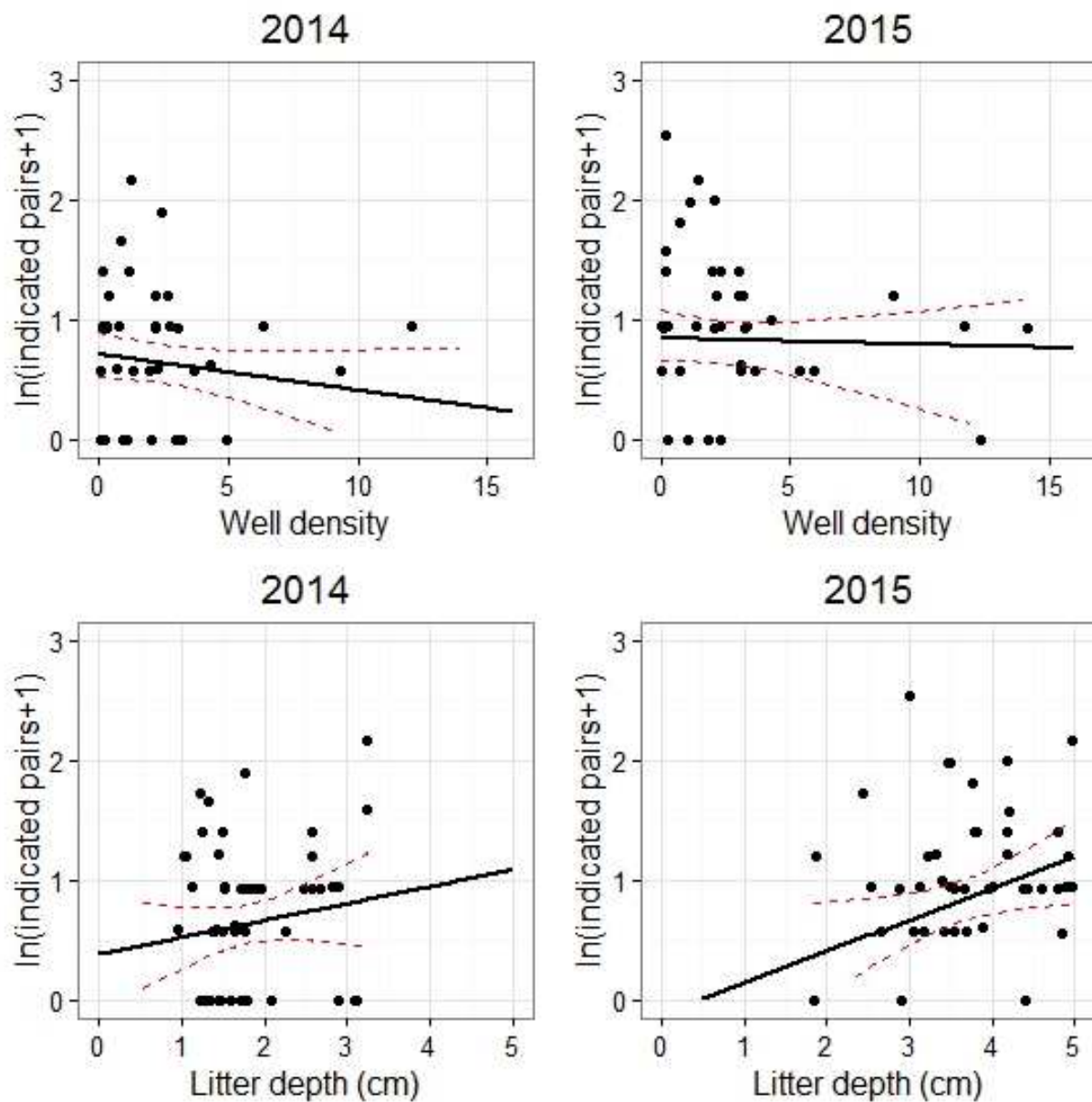


Figure 9. Model results showing relationship (black line with red-dashed 95% confidence intervals) between sharp-tailed grouse abundance and well density and litter depth (cm). Only strongly supported relationships are shown.

2.4.2.3. Upland sandpiper

The landscape model for upland sandpiper indicated that sandpiper densities were a function of Year and Percent.Grass ($\omega_i = 0.54$, Adj. $R^2 = 0.10$). The association, albeit weak, with Year and Percent.Grass indicates that Percent.Grass affects upland sandpiper abundance consistently between the two years (Table 8). One site-specific variable (Percent.BG) improved the best-supported landscape model ($\omega_i = 0.47$), which explained 16% of the variation in upland sandpiper abundance. The best site-specific model did not include an interaction between Percent.Grass or Percent.BG and Year, indicating that upland sandpiper densities were associated with Percent.Grass and Percent.BG but the direction and strength of the relationship did not vary with year. There is some evidence of an interaction between Year and Percent.BG ($\omega_i = 0.35$, Adj. $R^2 = 0.17$), but the site-specific model with the most weight and lowest Δ_i included only Year, Percent.Grass, and Percent.BG. Although many sites had zero abundance across the range of Percent.Grass and Percent.BG, upland sandpiper abundance tended to increase consistently with increasing grassland cover in the surrounding landscape (i.e., within 1.6 km of the study site) and increased with increasing bare ground cover in both years (Fig. 10).

2.4.2.4. Horned lark

Only Year was associated with horned lark densities at the landscape level (Table 9). There is good evidence suggesting that horned lark densities are associated with Year and Ltr.Depth ($\omega_i = 0.70$, Adj. $R^2 = 0.30$) at the site-specific level. Although horned larks were absent from many sites across the range of Ltr.Depth, horned lark abundance tended to decrease with increasing litter depth with this relationship being fairly consistent between the two years (Fig. 11).

Table 8. Model-selection results for models relating upland sandpiper abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC_c). Variable definitions are given in Table 1.

Model		K ¹	AIC _c	Δ_i ²	ω_i ³	RMSE ⁴	Adj. R ²
Landscape models:							
mod7	Year + Percent.Grass	4	214.4	0.0	0.54234	0.59730	0.10
mod10	Year + Year * Percent.Grass + Year * Roads	7	216.1	1.7	0.22655	0.58448	0.11
mod8	Year + Percent.Grass + Year * Percent.Grass	5	216.5	2.1	0.18558	0.59718	0.09
mod9	Year + Year * Percent.Grass + Year * Wells	7	220.5	6.2	0.02500	0.59589	0.08
mod5	Year + Roads	4	223.9	9.6	0.00456	0.62287	0.02
mod2	Year	3	224.1	9.7	0.00420	0.62922	0.01
mod1	Null	2	224.2	9.9	0.00393	0.63544	0.00
mod3	Year + Wells	4	224.4	10.0	0.00362	0.62413	0.02
mod6	Year + Roads + Year * Roads	5	225.6	11.2	0.00200	0.62141	0.02
mod4	Year + Wells + Year * Wells	5	226.2	11.8	0.00145	0.62315	0.01
mod11	Year + Year * Roads + Year * Wells	7	227.5	13.1	0.00077	0.61440	0.02
Best landscape model plus site-specific models:							
mod22	Year + Percent.Grass + Percent.BG	5	207.1	0.0	0.47086	0.57302	0.16
mod23	Year + Percent.Grass + Percent.BG + Year * Percent.BG	6	207.7	0.6	0.35714	0.56882	0.17
mod18	Year + Percent.Grass + Percent.AGCR	5	210.8	3.7	0.07531	0.58230	0.14
mod19	Year + Percent.Grass + Percent.AGCR + Year * Percent.AGCR	6	212.7	5.6	0.02936	0.58142	0.13
mod24	Year + Percent.Grass + Percent.Litter	5	213.8	6.7	0.01662	0.59007	0.11
mod7	Year + Percent.Grass	4	214.4	7.3	0.01240	0.59730	0.10
mod25	Year + Percent.Grass + Percent.Litter + Year * Percent.Litter	6	215.8	8.6	0.00626	0.58935	0.11
mod14	Year + Percent.Grass + Slope	5	216.2	9.1	0.00504	0.59628	0.10
mod26	Year + Percent.Grass + Ltr.Depth	5	216.3	9.1	0.00486	0.59647	0.09
mod12	Year + Percent.Grass + AvVOR	5	216.3	9.2	0.00467	0.59668	0.09
mod20	Year + Percent.Grass + Percent.POPR	5	216.5	9.4	0.00421	0.59722	0.09
mod16	Year + Percent.Grass + FQI	5	216.6	9.5	0.00416	0.59729	0.09
mod15	Year + Percent.Grass + Slope + Year * Slope	6	217.8	10.6	0.00230	0.59457	0.09
mod17	Year + Percent.Grass + FQI + Year * FQI	6	218.1	11.0	0.00191	0.59553	0.09
mod13	Year + Percent.Grass + AvVOR + Year * AvVOR	6	218.3	11.2	0.00174	0.59603	0.09
mod27	Year + Percent.Grass + Ltr.Depth + Year * Ltr.Depth	6	218.5	11.4	0.00160	0.59644	0.09
mod21	Year + Percent.Grass + Percent.POPR + Year * Percent.POPR	6	218.5	11.4	0.00157	0.59654	0.09

¹ Number of parameters.

² Delta AIC (measure of each model relative to the best model).

³ Akaike weights (measure of the strength of evidence for each model).

⁴ Root mean square error.

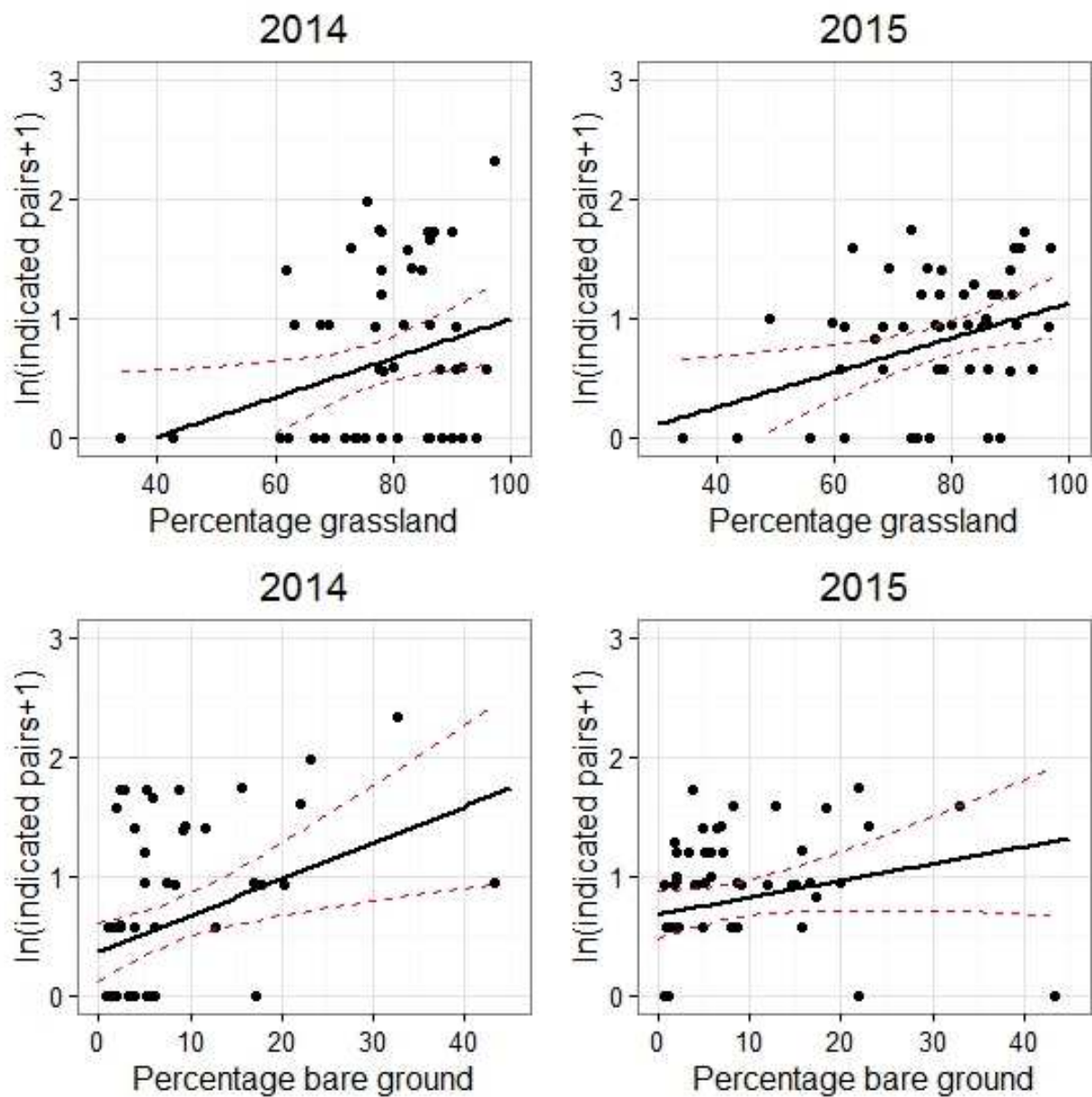


Figure 10. Model results showing relationship (black line with red-dashed 95% confidence intervals) between upland sandpiper abundance and percentage grassland and bare ground.

Table 9. Model-selection results for models relating horned lark abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC_c). Variable definitions are given in Table 1.

Model		K ¹	AIC _c	Δ_i ²	ω_i ³	RMSE ⁴	Adj. R ²
Landscape models:							
mod2	Year	3	285.5	0.0	0.22260	0.82353	0.01
mod1	Null	2	285.5	0.1	0.21655	0.83138	0.00
mod5	Year + Roads	4	286.5	1.0	0.13608	0.81933	0.01
mod3	Year + Wells	4	286.5	1.0	0.13538	0.81937	0.01
mod7	Year + Percent.Grass	4	287.4	1.9	0.08525	0.82270	0.00
mod6	Year + Roads + Year * Roads	5	287.5	2.1	0.07873	0.81541	0.01
mod4	Year + Wells + Year * Wells	5	288.5	3.1	0.04830	0.81891	0.00
mod8	Year + Percent.Grass + Year * Percent.Grass	5	288.9	3.5	0.03952	0.82035	0.00
mod11	Year + Year * Roads + Year * Wells	7	290.6	5.2	0.01681	0.81037	0.01
mod10	Year + Year * Percent.Grass + Year * Roads	7	291.4	6.0	0.01121	0.81326	0.00
mod9	Year + Year * Percent.Grass + Year * Wells	7	291.8	6.3	0.00957	0.81439	0.00
Best landscape model plus site-specific models:							
mod26	Year + Ltr.Depth	4	246.7	0.0	0.69716	0.68821	0.30
mod27	Year + Ltr.Depth + Year * Ltr.Depth	5	248.6	1.9	0.26844	0.68736	0.30
mod13	Year + AvVOR + Year * AvVOR	5	253.8	7.1	0.02010	0.70317	0.27
mod12	Year + AvVOR	4	254.5	7.8	0.01430	0.71207	0.25
mod24	Year + Percent.Litter	4	278.8	32.1	0.00000	0.79222	0.08
mod25	Year + Percent.Litter + Year * Percent.Litter	5	280.7	34.0	0.00000	0.79132	0.07
mod14	Year + Slope	4	281.9	35.3	0.00000	0.80329	0.05
mod15	Year + Slope + Year * Slope	5	283.0	36.3	0.00000	0.79936	0.05
mod2	Year	3	285.5	38.8	0.00000	0.82353	0.01
mod22	Year + Percent.BG	4	285.6	38.9	0.00000	0.81628	0.02
mod18	Year + Percent.AGCR	4	285.6	38.9	0.00000	0.81636	0.02
mod20	Year + Percent.POPR	4	286.5	39.8	0.00000	0.81953	0.01
mod23	Year + Percent.BG + Year * Percent.BG	5	287.2	40.5	0.00000	0.81402	0.02
mod16	Year + FQI	4	287.5	40.8	0.00000	0.82307	0.00
mod19	Year + Percent.AGCR + Year * Percent.AGCR	5	287.7	41.0	0.00000	0.81578	0.01
mod21	Year + Percent.POPR + Year * Percent.POPR	5	288.5	41.8	0.00000	0.81889	0.00
mod17	Year + FQI + Year * FQI	5	288.9	42.2	0.00000	0.82013	0.00

¹ Number of parameters.

² Delta AIC (measure of each model relative to the best model).

³ Akaike weights (measure of the strength of evidence for each model).

⁴ Root mean square error.

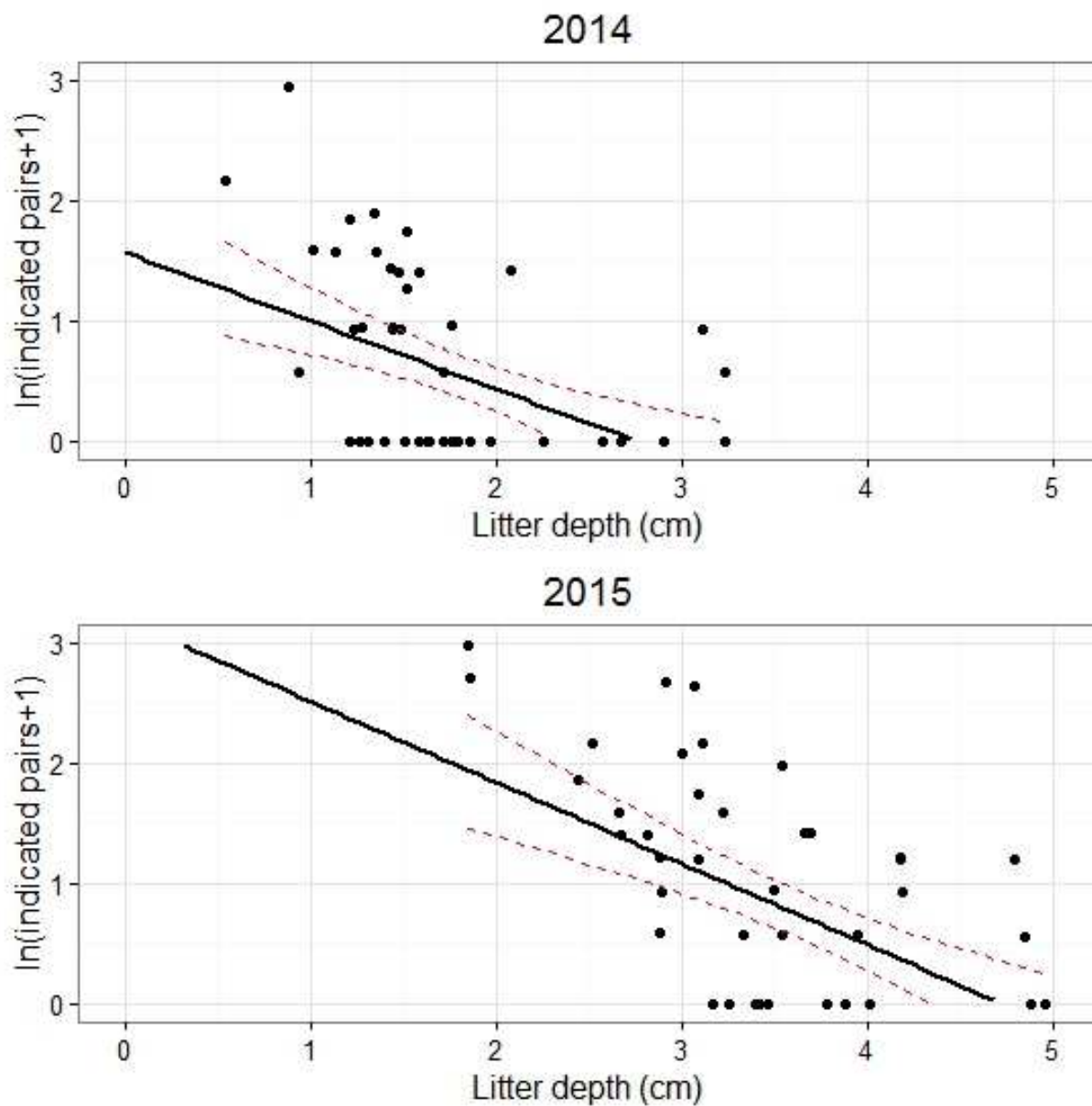


Figure 11. Model results showing relationship (black line with red-dashed 95% confidence intervals) between horned lark abundance and litter depth.

2.4.2.5. *Sprague's pipit*

For the Sprague's pipit, the best supported and most parsimonious landscape model, based on Δ_i and ω_i , included Year and Roads ($R^2 = 0.13$), indicating that Sprague's pipit abundance is weakly associated with roads and that this association is consistent between the two years (Table 10). There is some evidence ($\omega_i = 0.22$, Adj. $R^2 = 0.12$) that Sprague's pipit densities are associated with the interaction between Year and Roads, but the landscape model with the most weight included only Year and Roads. One site-specific variable (AvVOR) improved the landscape model ($\omega_i = 0.60$, $R^2 = 0.23$). Within the range of roads and VOR sampled, Sprague's pipit abundance declines with increasing road densities and VOR. These declines were fairly consistent from year-to-year (Fig. 12).

2.4.2.6. *Clay-colored sparrow*

For the clay-colored sparrow, the best supported and most parsimonious landscape model included Year, the interaction between Year and Percent.Grass, and the interaction between Year and Wells. This indicated that clay-colored sparrow abundance is associated with the percentage of grassland and density of wells within 1.6 km of the study site and that this association varied between the two years (Table 11). One site-specific variable (FQI) improved the best-supported landscape model ($\omega_i = 0.38$, $R^2 = 0.31$). The best site-specific model included all of the interactions from the best landscape model but did not include interactions between the site-specific variable (FQI) and Year, indicating that clay-colored sparrow densities were associated with FQI and the strength of the relationship did not vary with year. Across the range of grassland cover sampled, Clay-colored sparrow abundance decreased with increasing grassland cover, especially in 2014 (Fig. 13). Abundance also tended to increase with increasing well density and increasing FQI.

Table 10. Model-selection results for models relating Sprague's pipit abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC_c). Variable definitions are given in Table 1.

Model		K ¹	AIC _C	Δ_i ²	ω_i ³	RMSE ⁴	Adj. R ²
Landscape models:							
mod5	Year + Roads	4	274.1	0.0	0.67242	0.77618	0.13
mod6	Year + Roads + Year * Roads	5	276.3	2.2	0.22625	0.77614	0.12
mod10	Year + Year * Percent.Grass + Year * Roads	7	278.6	4.5	0.07252	0.76860	0.12
mod11	Year + Year * Roads + Year * Wells	7	280.6	6.4	0.02678	0.77535	0.11
mod1	Null	2	287.6	13.5	0.00078	0.83909	0.00
mod7	Year + Percent.Grass	4	288.3	14.2	0.00056	0.82593	0.01
mod2	Year	3	289.5	15.4	0.00030	0.83828	-0.01
mod8	Year + Percent.Grass + Year * Percent.Grass	5	290.4	16.3	0.00020	0.82565	0.01
mod3	Year + Wells	4	291.6	17.4	0.00011	0.83789	-0.02
mod4	Year + Wells + Year * Wells	5	293.6	19.4	0.00004	0.83717	-0.02
mod9	Year + Year * Percent.Grass + Year * Wells	7	294.5	20.4	0.00002	0.82433	-0.01
Best landscape model plus site-specific models:							
mod12	Year + Roads + AvVOR	5	261.5	0.0	0.59542	0.72728	0.23
mod13	Year + Roads + AvVOR + Year * AvVOR	6	262.9	1.4	0.28838	0.72480	0.23
mod26	Year + Roads + Ltr.Depth	5	266.8	5.3	0.04182	0.74443	0.19
mod24	Year + Roads + Percent.Litter	5	267.2	5.8	0.03349	0.74588	0.19
mod27	Year + Roads + Ltr.Depth + Year * Ltr.Depth	6	268.9	7.5	0.01418	0.74421	0.18
mod25	Year + Roads + Percent.Litter + Year * Percent.Litter	6	269.2	7.8	0.01217	0.74521	0.18
mod14	Year + Roads + Slope	5	271.3	9.8	0.00437	0.75931	0.16
mod16	Year + Roads + FQI	5	271.6	10.1	0.00383	0.76020	0.16
mod17	Year + Roads + FQI + Year * FQI	6	272.7	11.3	0.00213	0.75668	0.16
mod15	Year + Roads + Slope + Year * Slope	6	273.5	12.1	0.00144	0.75931	0.15
mod5	Year + Roads	4	274.1	12.6	0.00107	0.77618	0.13
mod18	Year + Roads + Percent.AGCR	5	275.7	14.2	0.00049	0.77406	0.13
mod22	Year + Roads + Percent.BG	5	276.1	14.7	0.00039	0.77561	0.12
mod20	Year + Roads + Percent.POPR	5	276.2	14.7	0.00038	0.77579	0.12
mod19	Year + Roads + Percent.AGCR + Year * Percent.AGCR	6	277.9	16.4	0.00017	0.77385	0.12
mod21	Year + Roads + Percent.POPR + Year * Percent.POPR	6	278.1	16.7	0.00014	0.77485	0.12
mod23	Year + Roads + Percent.BG + Year * Percent.BG	6	278.3	16.8	0.00013	0.77543	0.11

¹ Number of parameters.

² Delta AIC (measure of each model relative to the best model).

³ Akaike weights (measure of the strength of evidence for each model).

⁴ Root mean square error.

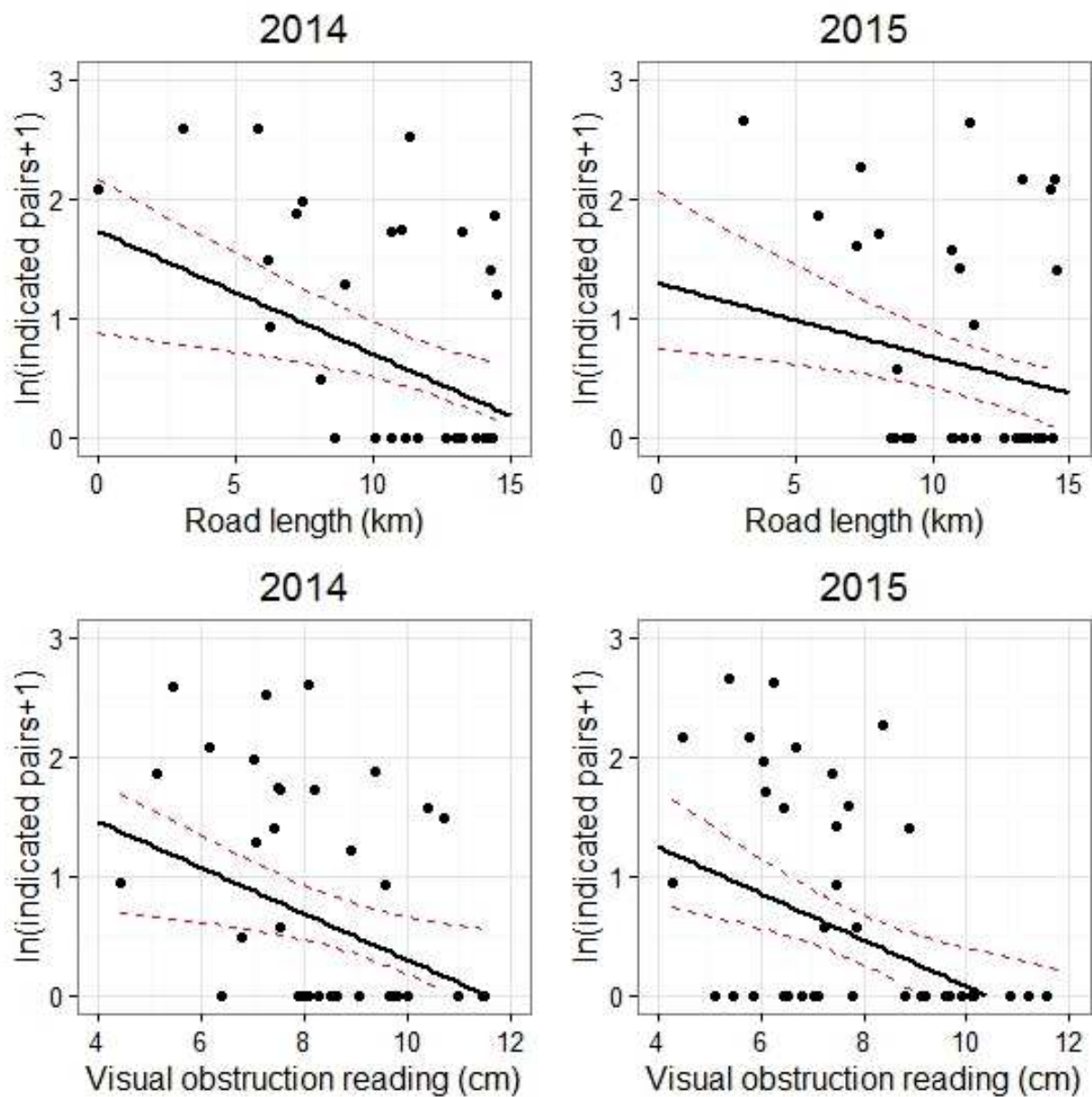


Figure 12. Model results showing relationship (black line with red-dashed 95% confidence intervals) between Sprague's pipit abundance and road length and visual obstruction reading.

Table 11. Model-selection results for models relating clay-colored sparrow abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC_c). Variable definitions are given in Table 1.

Model		K ¹	AIC _c	Δ_i ²	ω_i ³	RMSE ⁴	Adj. R ²
Landscape models:							
mod9	Year + Year * Percent.Grass + Year * Wells	7	272.8	0.0	0.94035	0.74942	0.25
mod7	Year + Percent.Grass	4	279.4	6.6	0.03522	0.79429	0.18
mod8	Year + Percent.Grass + Year * Percent.Grass	5	281.5	8.7	0.01201	0.79416	0.17
mod3	Year + Wells	4	282.4	9.6	0.00790	0.79334	0.16
mod4	Year + Wells + Year * Wells	5	284.5	11.7	0.00269	0.80477	0.16
mod10	Year + Year * Percent.Grass + Year * Roads	7	285.8	13.0	0.00142	0.80465	0.15
mod11	Year + Year * Roads + Year * Wells	7	288.4	15.5	0.00040	0.80230	0.14
mod1	Null	2	299.7	26.9	0.00000	0.88465	0.00
mod2	Year	3	301.8	29.0	0.00000	0.88465	-0.01
mod5	Year + Roads	4	303.0	30.1	0.00000	0.88083	-0.01
mod6	Year + Roads + Year * Roads	5	305.1	32.3	0.00000	0.88080	-0.02
Best landscape model plus site-specific models:							
mod16	Year + Year * Percent.Grass + Year * Wells + FQI	8	264.3	0.0	0.38695	0.71460	0.31
mod26	Year + Year * Percent.Grass + Year * Wells + Ltr.Depth	8	265.8	1.5	0.18401	0.71928	0.30
mod17	Year + Year * Percent.Grass + Year * Wells + FQI + Year * FQI	9	266.6	2.3	0.12021	0.71454	0.30
mod27	Year + Year * Percent.Grass + Year * Wells + Ltr.Depth + Year * Ltr.Depth	9	266.6	2.4	0.11883	0.71461	0.30
mod12	Year + Year * Percent.Grass + Year * Wells + AvVOR	8	267.2	2.9	0.09125	0.72372	0.29
mod18	Year + Year * Percent.Grass + Year * Wells + Percent.AGCR	8	269.0	4.8	0.03563	0.72971	0.28
mod13	Year + Year * Percent.Grass + Year * Wells + AvVOR + Year * AvVOR	9	269.3	5.1	0.03092	0.72310	0.29
mod19	Year + Year * Percent.Grass + Year * Wells + Percent.AGCR + Year * Percent.AGCR	9	271.0	6.8	0.01322	0.72851	0.28
mod9	Year + Year * Percent.Grass + Year * Wells	7	272.8	8.5	0.00544	0.74942	0.25
mod20	Year + Year * Percent.Grass + Year * Wells + Percent.POPR	8	273.4	9.1	0.00409	0.74371	0.25
mod22	Year + Year * Percent.Grass + Year * Wells + Percent.BG	8	274.7	10.4	0.00212	0.74800	0.24
mod14	Year + Year * Percent.Grass + Year * Wells + Slope	8	274.9	10.7	0.00186	0.74884	0.24
mod24	Year + Year * Percent.Grass + Year * Wells + Percent.Litter	8	275.0	10.8	0.00178	0.74916	0.24
mod21	Year + Year * Percent.Grass + Year * Wells + Percent.POPR + Year * Percent.POPR	9	275.6	11.4	0.00133	0.74335	0.25
mod25	Year + Year * Percent.Grass + Year * Wells + Percent.Litter + Year * Percent.Litter	9	276.5	12.2	0.00088	0.74606	0.24
mod15	Year + Year * Percent.Grass + Year * Wells + Slope + Year * Slope	9	276.7	12.4	0.00079	0.74677	0.24
mod23	Year + Year * Percent.Grass + Year * Wells + Percent.BG + Year * Percent.BG	9	276.9	12.6	0.00072	0.74737	0.24

¹ Number of parameters.

² Delta AIC (measure of each model relative to the best model).

³ Akaike weights (measure of the strength of evidence for each model).

⁴ Root mean square error.

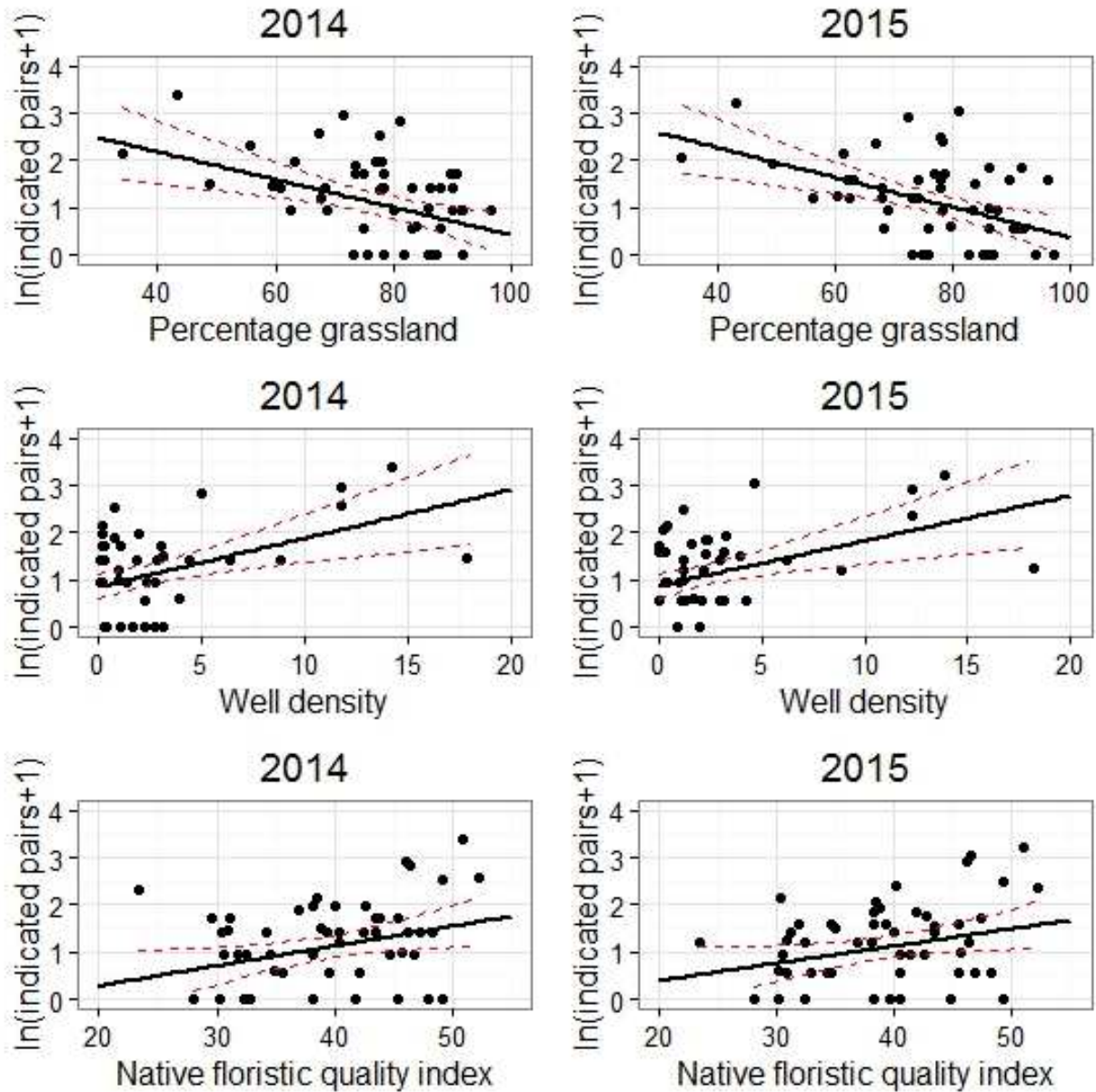


Figure 13. Model results showing relationship (black line with red-dashed 95% confidence intervals) between clay-colored sparrow abundance and percentage grassland, well density, and FQI.

2.4.2.7. *Field sparrow*

The best supported and most parsimonious landscape model, albeit weak ($\omega_i = 0.63$, $R^2 = 0.07$), for field sparrow abundance included Year and Percent.Grass (Table 12). One site-specific variable (Percent.AGCR) improved the best-supported landscape model ($\omega_i = 0.66$). However, the final model only explained 16% of variation in field sparrow abundance. The best site-specific model did not include any interactions with year, and thus the relationship between field sparrow abundance and the explanatory variables did not vary with year. Although many sites had zero abundance across the range of Percent.Grass and Percent.AGCR, field sparrow abundance tended to decline with increasing percentage of grassland in the surrounding landscape and the percentage of crested wheatgrass at the site level (Fig. 14).

2.4.2.8. *Vesper sparrow*

The best supported and most parsimonious landscape model for the vesper sparrow based on Δ_i and ω_i , included Year and Wells ($R^2 = 0.07$), indicating that vesper sparrow abundance is weakly associated with the density of wells within 1.6 km of the study site and that this association is fairly consistent between the two years (Table 13). One site-specific variable (FQI) improved the best-supported landscape model ($\omega_i = 0.24$, $R^2 = 0.17$). There also is evidence that the association between vesper sparrow abundance and FQI varies from year-to-year ($\omega_i = 0.22$, Adj. $R^2 = 0.18$); however, the best model based on Δ_i does not include this interaction. Although many sites had zero abundance across the range of Wells and FQI, vesper sparrow abundance tended to decrease with increasing oil well density in the surrounding landscape and FQI at the site level, with some tendency for the relationship to be stronger in 2015 (Fig. 15).

Table 12. Model-selection results for models relating field sparrow abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC_c). Variable definitions are given in Table 1.

Model		K ¹	AIC _c	Δ_i ²	ω_i ³	RMSE ⁴	Adj. R ²
Landscape models:							
mod7	Year + Percent.Grass	4	284.0	0.0	0.63184	0.81044	0.07
mod8	Year + Percent.Grass + Year * Percent.Grass	5	285.9	1.9	0.23980	0.80955	0.06
mod10	Year + Year * Percent.Grass + Year * Roads	7	289.7	5.7	0.03566	0.80710	0.05
mod9	Year + Year * Percent.Grass + Year * Wells	7	289.9	5.9	0.03266	0.80773	0.05
mod1	Null	2	290.2	6.2	0.02856	0.84846	0.00
mod2	Year	3	291.9	8.0	0.01180	0.84718	-0.01
mod5	Year + Roads	4	292.8	8.8	0.00766	0.84243	0.00
mod3	Year + Wells	4	293.3	9.3	0.00602	0.84421	-0.01
mod4	Year + Wells + Year * Wells	5	294.8	10.9	0.00277	0.84211	-0.01
mod6	Year + Roads + Year * Roads	5	294.9	10.9	0.00268	0.84185	-0.01
mod11	Year + Year * Roads + Year * Wells	7	298.1	14.1	0.00055	0.83724	-0.02
Best landscape model plus site-specific models:							
mod18	Year + Percent.Grass + Percent.AGCR	5	273.2	0.0	0.66040	0.76560	0.16
mod19	Year + Percent.Grass + Percent.AGCR + Year * Percent.AGCR	6	275.1	1.9	0.24948	0.76465	0.16
mod14	Year + Percent.Grass + Slope	5	278.7	5.6	0.04072	0.78454	0.12
mod15	Year + Percent.Grass + Slope + Year * Slope	6	280.9	7.8	0.01360	0.78442	0.11
mod16	Year + Percent.Grass + FQI	5	281.5	8.3	0.01023	0.79411	0.10
mod12	Year + Percent.Grass + AvVOR	5	283.0	9.9	0.00478	0.79943	0.09
mod20	Year + Percent.Grass + Percent.POPR	5	283.4	10.2	0.00398	0.80071	0.09
mod17	Year + Percent.Grass + FQI + Year * FQI	6	283.5	10.3	0.00374	0.79336	0.09
mod7	Year + Percent.Grass	4	284.0	10.8	0.00300	0.81044	0.07
mod26	Year + Percent.Grass + Ltr.Depth	5	284.1	11.0	0.00276	0.80329	0.08
mod13	Year + Percent.Grass + AvVOR + Year * AvVOR	6	285.2	12.0	0.00164	0.79911	0.08
mod22	Year + Percent.Grass + Percent.BG	5	285.4	12.2	0.00146	0.80779	0.07
mod21	Year + Percent.Grass + Percent.POPR + Year * Percent.POPR	6	285.6	12.4	0.00133	0.80057	0.08
mod24	Year + Percent.Grass + Percent.Litter	5	286.1	12.9	0.00104	0.81020	0.06
mod27	Year + Percent.Grass + Ltr.Depth + Year * Ltr.Depth	6	286.2	13.0	0.00099	0.80268	0.07
mod23	Year + Percent.Grass + Percent.BG + Year * Percent.BG	6	287.5	14.3	0.00051	0.80730	0.06
mod25	Year + Percent.Grass + Percent.Litter + Year * Percent.Litter	6	288.3	15.1	0.00034	0.81013	0.05

¹ Number of parameters.

² Delta AIC (measure of each model relative to the best model).

³ Akaike weights (measure of the strength of evidence for each model).

⁴ Root mean square error.

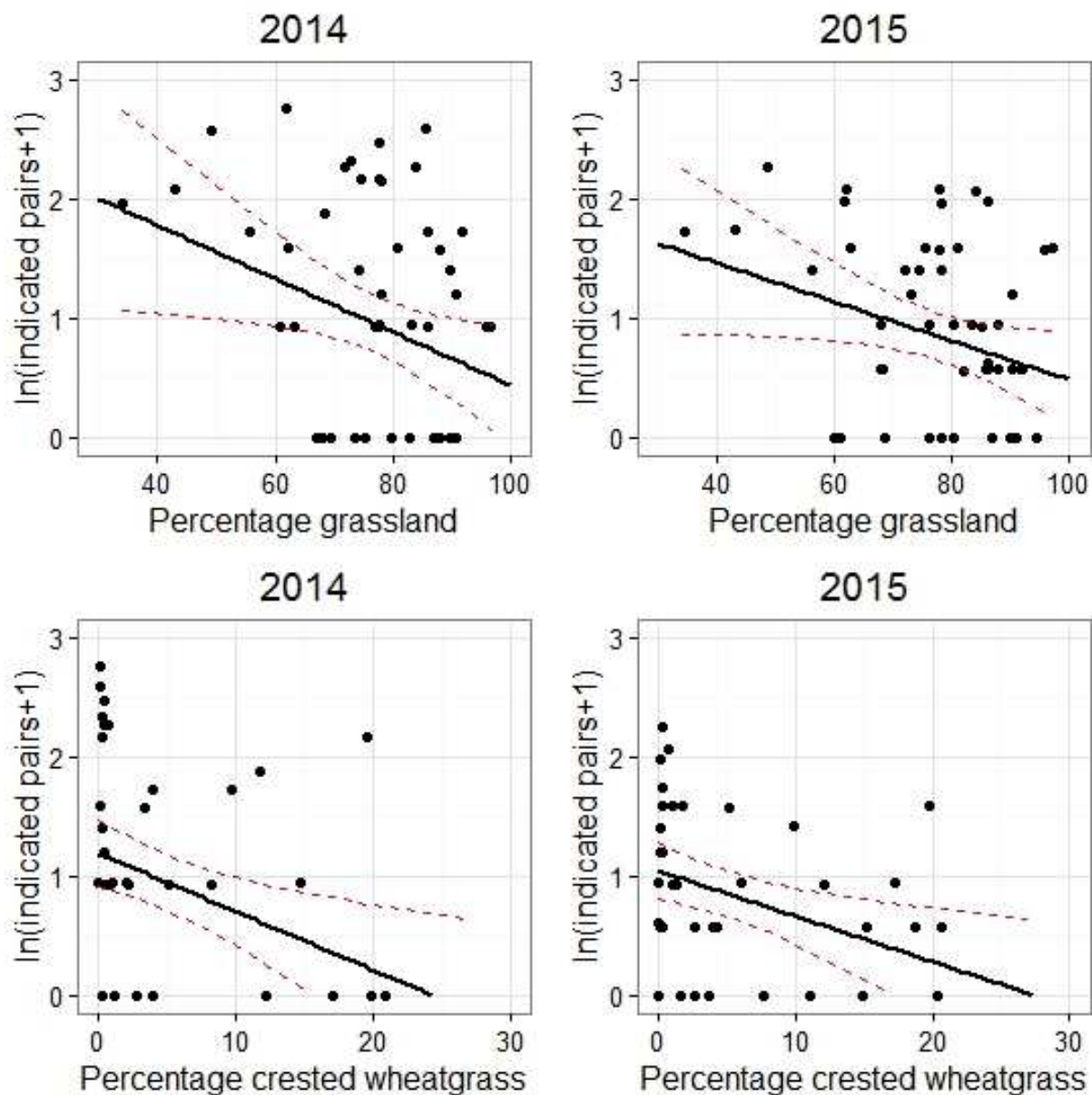


Figure 14. Model results showing relationship (black line with red-dashed 95% confidence intervals) between field sparrow abundance and percentage grassland and crested wheatgrass.

Table 13. Model-selection results for models relating vesper sparrow abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC_c). Variable definitions are given in Table 1.

Model		K ¹	AIC _c	Δ_i ²	ω_i ³	RMSE ⁴	Adj. R ²
Landscape models:							
mod3	Year + Wells	4	222.9	0.0	0.33684	0.62003	0.07
mod4	Year + Wells + Year * Wells	5	223.5	0.6	0.24861	0.61575	0.08
mod2	Year	3	225.3	2.4	0.10332	0.63242	0.04
mod7	Year + Percent.Grass	4	225.4	2.5	0.09527	0.62694	0.05
mod5	Year + Roads	4	226.4	3.4	0.06006	0.62948	0.04
mod11	Year + Year * Roads + Year * Wells	7	227.0	4.1	0.04248	0.62661	0.04
mod9	Year + Year * Percent.Grass + Year * Wells	7	227.3	4.4	0.03697	0.61314	0.07
mod8	Year + Percent.Grass + Year * Percent.Grass	5	227.5	4.6	0.03385	0.61389	0.06
mod6	Year + Roads + Year * Roads	5	228.4	5.5	0.02148	0.62911	0.03
mod1	Null	2	229.0	6.1	0.01562	0.64897	0.00
mod10	Year + Year * Percent.Grass + Year * Roads	7	231.1	8.2	0.00551	0.62422	0.03
Best landscape model plus site-specific models:							
mod16	Year + Wells + FQI	5	210.5	0.0	0.24085	0.58160	0.17
mod17	Year + Wells + FQI + Year * FQI	6	210.7	0.1	0.22352	0.57632	0.18
mod14	Year + Wells + Slope	5	210.7	0.2	0.22072	0.58205	0.17
mod19	Year + Wells + Percent.AGCR + Year * Percent.AGCR	6	211.0	0.5	0.18398	0.57730	0.18
mod15	Year + Wells + Slope + Year * Slope	6	212.8	2.3	0.07681	0.58174	0.17
mod18	Year + Wells + Percent.AGCR	5	213.8	3.3	0.04686	0.59001	0.15
mod24	Year + Wells + Percent.Litter	5	218.7	8.2	0.00405	0.60282	0.11
mod25	Year + Wells + Percent.Litter + Year * Percent.Litter	6	220.6	10.1	0.00156	0.60198	0.11
mod3	Year + Wells	4	222.9	12.4	0.00049	0.62003	0.07
mod12	Year + Wells + AvVOR	5	224.1	13.6	0.00026	0.61743	0.07
mod26	Year + Wells + Ltr.Depth	5	224.8	14.3	0.00019	0.61929	0.06
mod22	Year + Wells + Percent.BG	5	224.9	14.4	0.00018	0.61960	0.06
mod20	Year + Wells + Percent.POPR	5	225.1	14.6	0.00017	0.61995	0.06
mod21	Year + Wells + Percent.POPR + Year * Percent.POPR	6	225.4	14.9	0.00014	0.61480	0.07
mod13	Year + Wells + AvVOR + Year * AvVOR	6	226.0	15.5	0.00011	0.61638	0.06
mod27	Year + Wells + Ltr.Depth + Year * Ltr.Depth	6	227.0	16.5	0.00006	0.61907	0.06
mod23	Year + Wells + Percent.BG + Year * Percent.BG	6	227.2	16.7	0.00006	0.61959	0.06

¹ Number of parameters.

² Delta AIC (measure of each model relative to the best model).

³ Akaike weights (measure of the strength of evidence for each model).

⁴ Root mean square error.

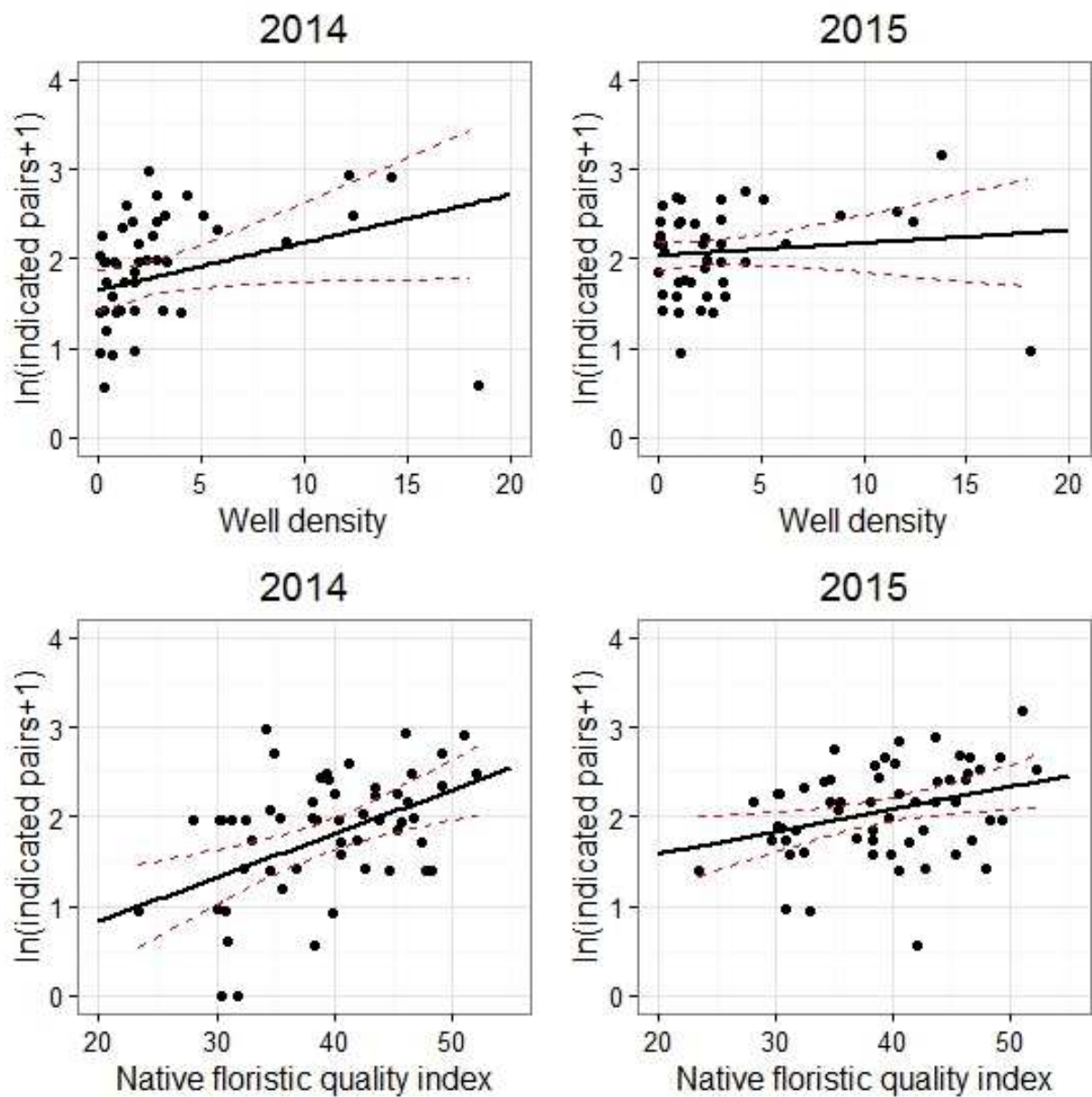


Figure 15. Model results showing relationship (black line with red-dashed 95% confidence intervals) between vesper sparrow abundance and well density and FQI.

2.4.2.9. Grasshopper sparrow

Grasshopper sparrow densities were not associated with any of the landscape variables (i.e., none of the landscape-level models was better than the null model; Table 14). The best site-specific model included Year and Slope ($\omega_i = 0.67$, Adj. $R^2 = 0.07$). Grasshopper sparrow densities tended to decline with increasing Slope; this relationship was consistent between the two years but variation in abundance was slightly greater in 2014 (Fig. 16).

2.4.2.10. Baird's sparrow

For the Baird's sparrow, the best supported and most parsimonious landscape model, based on Δ_i and ω_i , included Year and Roads ($R^2 = 0.10$), indicating that Baird's sparrow abundance is weakly associated with roads and that this association is consistent between the two years (Table 15). However, there is some evidence ($\omega_i = 0.31$, Adj. $R^2 = 0.12$) that Baird's sparrow densities are associated with Percent.Grass and the interaction between Year and Percent.Grass (i.e., the percentage of grassland within 1.6 km of the sample-unit) and Year and Roads, but the landscape model with the most weight included only Year and Roads. One site-specific variable (Slope) improved the best-supported landscape model ($\omega_i = 0.75$). The best site-specific model did not include interactions between Slope and Year, indicating that Baird's sparrow densities were associated with Roads and Slope but the direction and strength of the relationship did not vary with year. The final model explained 27% of the variation in Baird's sparrow abundance. Although many sites had zero abundance across the range of Roads and Slope, Baird's sparrow abundance tended to decline with increasing road density and increasing slope (Fig. 17).

Table 14. Model-selection results for models relating grasshopper sparrow abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC_c). Variable definitions are given in Table 1.

Model		K^1	AIC_c	Δ_i^2	ω_i^3	RMSE ⁴	Adj. R ²
Landscape models:							
mod1	Null	2	113.5	0.0	0.49800	0.39101	0.00
mod2	Year	3	115.6	2.1	0.17694	0.39094	-0.01
mod5	Year + Roads	4	117.2	3.7	0.08002	0.38997	-0.01
mod3	Year + Wells	4	117.5	4.0	0.06749	0.39056	-0.02
mod7	Year + Percent.Grass	4	117.7	4.2	0.06162	0.39087	-0.02
mod6	Year + Roads + Year * Roads	5	118.7	5.2	0.03717	0.38886	-0.02
mod4	Year + Wells + Year * Wells	5	118.9	5.4	0.03358	0.38969	-0.02
mod8	Year + Percent.Grass + Year * Percent.Grass	5	119.2	5.7	0.02915	0.38920	-0.02
mod11	Year + Year * Roads + Year * Wells	7	122.2	8.7	0.00642	0.38717	-0.03
mod10	Year + Year * Percent.Grass + Year * Roads	7	122.6	9.1	0.00538	0.38777	-0.03
mod9	Year + Year * Percent.Grass + Year * Wells	7	123.1	9.5	0.00423	0.38860	-0.03
Best landscape model plus site-specific models:							
mod14	Year + Slope	4	107.4	0.0	0.67240	0.37353	0.07
mod15	Year + Slope + Year * Slope	5	109.5	2.2	0.22520	0.37353	0.06
mod1	Null	2	113.5	6.2	0.03080	0.39101	0.00
mod22	Year + Percent.BG	4	115.3	7.9	0.01276	0.38675	0.00
mod26	Year + Ltr.Depth	4	115.7	8.3	0.01036	0.38746	0.00
mod18	Year + Percent.AGCR	4	116.5	9.1	0.00707	0.38876	-0.01
mod20	Year + Percent.POPR	4	116.7	9.3	0.00628	0.38916	-0.01
mod16	Year + FQI	4	116.7	9.4	0.00616	0.38922	-0.01
mod12	Year + AvVOR	4	117.0	9.6	0.00556	0.38958	-0.01
mod23	Year + Percent.BG + Year * Percent.BG	5	117.1	9.8	0.00512	0.38614	0.00
mod24	Year + Percent.Litter	4	117.6	10.2	0.00412	0.39061	-0.02
mod27	Year + Ltr.Depth + Year * Ltr.Depth	5	117.7	10.4	0.00373	0.38721	-0.01
mod21	Year + Percent.POPR + Year * Percent.POPR	5	118.5	11.2	0.00253	0.38853	-0.01
mod19	Year + Percent.AGCR + Year * Percent.AGCR	5	118.7	11.3	0.00237	0.38875	-0.02
mod17	Year + FQI + Year * FQI	5	118.9	11.5	0.00214	0.38910	-0.02
mod13	Year + AvVOR + Year * AvVOR	5	119.0	11.6	0.00200	0.38933	-0.02
mod25	Year + Percent.Litter + Year * Percent.Litter	5	119.7	12.4	0.00140	0.39055	-0.02

¹ Number of parameters.

² Delta AIC (measure of each model relative to the best model).

³ Akaike weights (measure of the strength of evidence for each model).

⁴ Root mean square error.

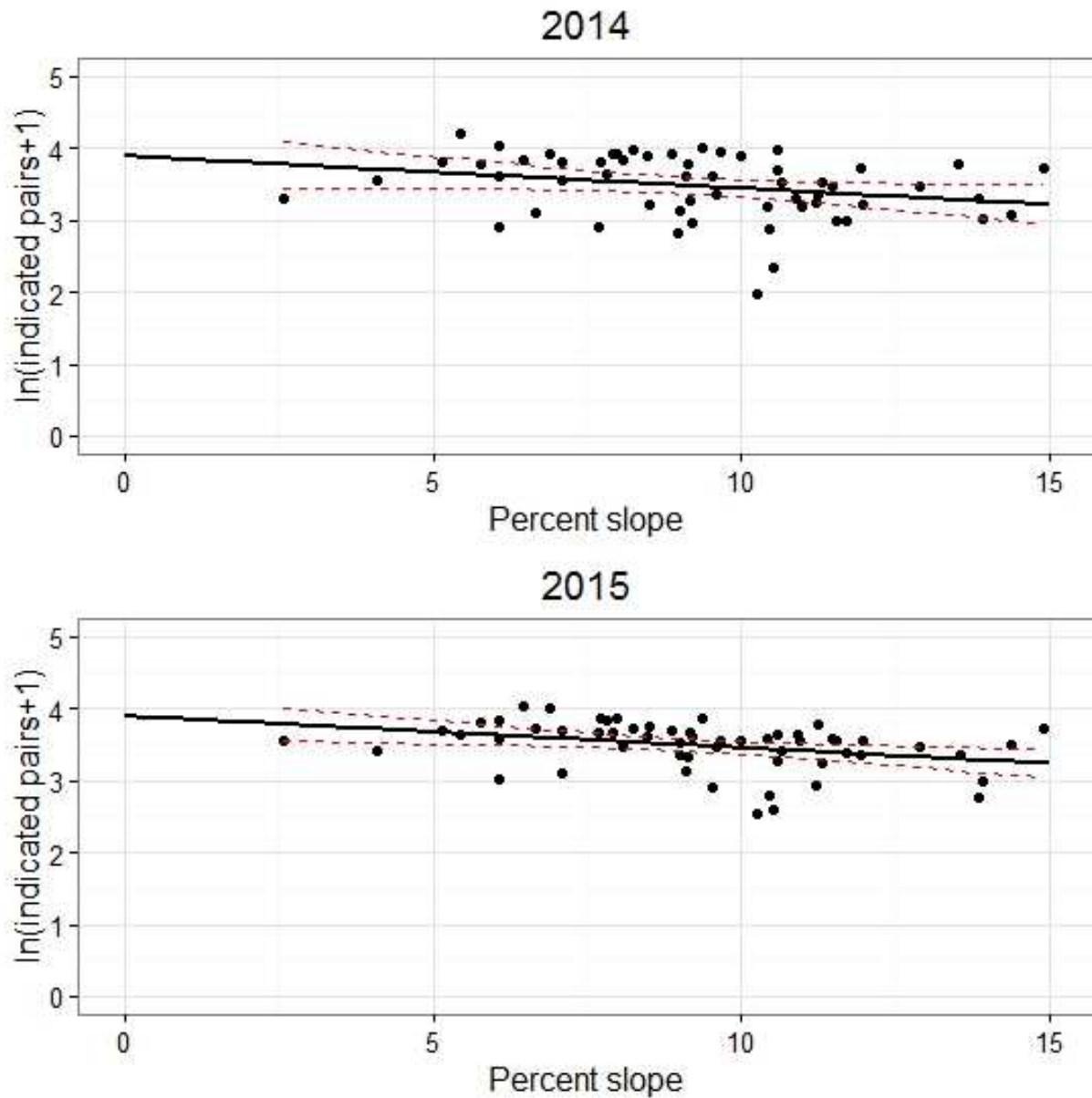


Figure 16. Model results showing relationship (black line with red-dashed 95% confidence intervals) between grasshopper sparrow abundance and slope.

Table 15. Model-selection results for models relating Baird's sparrow sparrow abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC_c). Variable definitions are given in Table 1.

Model		K ¹	AIC _C	Δ_i ²	ω_i ³	RMSE ⁴	Adj. R ²
Landscape models:							
mod5	Year + Roads	4	259.4	0.0	0.41658	0.72754	0.10
mod10	Year + Year * Percent.Grass + Year * Roads	7	259.9	0.6	0.31183	0.70830	0.12
mod6	Year + Roads + Year * Roads	5	260.9	1.5	0.19606	0.72537	0.10
mod11	Year + Year * Roads + Year * Wells	7	263.2	3.9	0.05961	0.71866	0.10
mod7	Year + Percent.Grass	4	267.9	8.5	0.00584	0.75529	0.03
mod8	Year + Percent.Grass + Year * Percent.Grass	5	268.6	9.3	0.00405	0.75048	0.04
mod1	Null	2	269.3	10.0	0.00288	0.77432	0.00
mod2	Year	3	271.1	11.8	0.00116	0.77333	-0.01
mod3	Year + Wells	4	271.6	12.2	0.00092	0.76761	0.00
mod9	Year + Year * Percent.Grass + Year * Wells	7	272.4	13.0	0.00061	0.74810	0.02
mod4	Year + Wells + Year * Wells	5	273.0	13.7	0.00045	0.76510	0.00
Best landscape model plus site-specific models:							
mod14	Year + Roads + Slope	5	236.4	0	0.74962	0.65147	0.27
mod15	Year + Roads + Slope + Year * Slope	6	238.6	2.2	0.25023	0.65137	0.27
mod12	Year + Roads + AvVOR	5	255.5	19.1	0.00005	0.70846	0.14
mod26	Year + Roads + Ltr.Depth	5	257.2	20.9	0.00002	0.71392	0.13
mod24	Year + Roads + Percent.Litter	5	257.5	21.2	0.00002	0.71488	0.12
mod13	Year + Roads + AvVOR + Year * AvVOR	6	257.7	21.3	0.00002	0.70836	0.13
mod5	Year + Roads	4	259.4	23	0.00001	0.72754	0.10
mod27	Year + Roads + Ltr.Depth + Year * Ltr.Depth	6	259.5	23.1	0.00001	0.71389	0.12
mod25	Year + Roads + Percent.Litter + Year * Percent.Litter	6	259.7	23.3	0.00001	0.71468	0.12
mod20	Year + Roads + Percent.POPR	5	260.4	24.1	0.00000	0.72401	0.10
mod16	Year + Roads + FQI	5	260.5	24.1	0.00000	0.72410	0.10
mod22	Year + Roads + Percent.BG	5	260.6	24.2	0.00000	0.72446	0.10
mod18	Year + Roads + Percent.AGCR	5	261.5	25.1	0.00000	0.72733	0.09
mod23	Year + Roads + Percent.BG + Year * Percent.BG	6	262.1	25.8	0.00000	0.72227	0.10
mod17	Year + Roads + FQI + Year * FQI	6	262.6	26.2	0.00000	0.72382	0.09
mod21	Year + Roads + Percent.POPR + Year * Percent.POPR	6	262.7	26.3	0.00000	0.72397	0.09
mod19	Year + Roads + Percent.AGCR + Year * Percent.AGCR	6	263.3	26.9	0.00000	0.72592	0.09

¹ Number of parameters.

² Delta AIC (measure of each model relative to the best model).

³ Akaike weights (measure of the strength of evidence for each model).

⁴ Root mean square error.

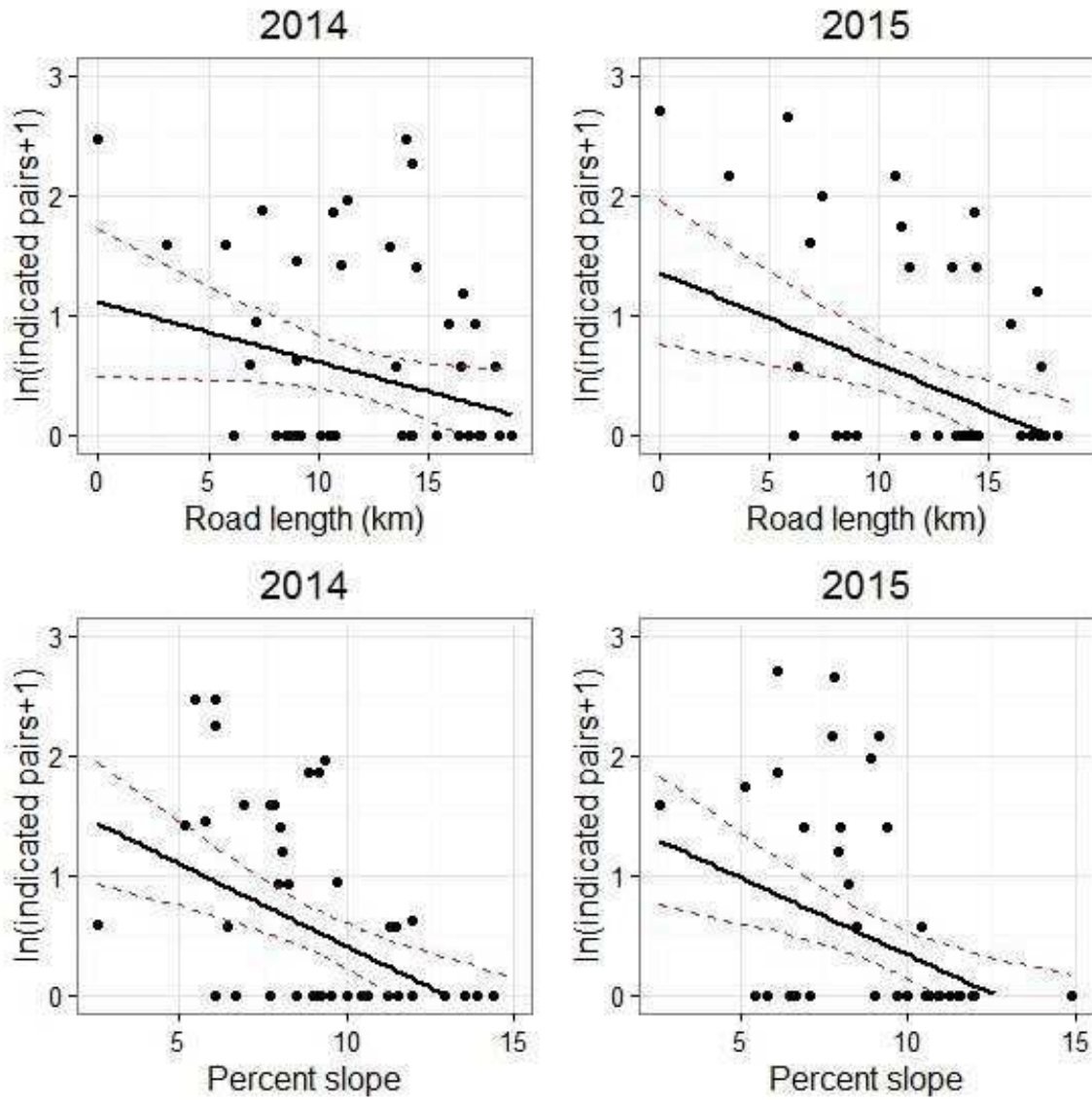


Figure 17. Model results showing relationship (black line with red-dashed 95% confidence intervals) between Baird's sparrow abundance and road length and slope.

2.4.2.11. Chestnut-collared longspur

For the chestnut-collared longspur, the best supported and most parsimonious landscape model, based on Δ_i and ω_i , included Year and Percent.Grass ($R^2 = 0.09$), indicating that longspur abundance is weakly associated with the percentage of grassland in the surrounding landscape (i.e., within 1.6 km of the study unit boundary) and that this association is consistent between the two years (Table 16). There is some evidence ($\omega_i = 0.20$, Adj. $R^2 = 0.10$) that chestnut-collared longspur densities are associated with Year and the interactions between Year and Percent.Grass and Year and Roads, but the landscape model with the most weight included only Year and Percent.Grass. One site-specific variable (AvVOR) improved the best-supported landscape model ($\omega_i = 0.41$). The best site-specific model did not include interactions between AvVOR and Year, indicating that chestnut-collared longspur densities were associated with Percent.Grass and AvVOR but the direction and strength of the relationship did not vary with year. The final model explained 22% of the variation in chestnut-collared longspur abundance. Although the chestnut-collared longspur was the least common of the 12 focal species, its abundance tended to increase with increasing grassland coverage around the site and decreased with increasing VOR (Fig. 18).

2.4.2.12. Bobolink

Bobolink densities were not associated with any of the landscape variables (i.e., none of the landscape-level models was better than the null model; Table 17). The best supported model using site-specific variables included Year and Slope. Bobolink densities tended to decline with increasing Slope (Adj. $R^2 = 0.22$); this relationship was consistent between the two years (Fig. 19).

Table 16. Model-selection results for models relating chestnut-collared longspur abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC_c). Variable definitions are given in Table 1.

Model		K ¹	AIC _c	Δ_i ²	ω_i ³	RMSE ⁴	Adj. R ²
Landscape models:							
mod7	Year + Percent.Grass	4	284.8	0.0	0.52391	0.81324	0.09
mod10	Year + Year * Percent.Grass + Year * Roads	7	286.7	1.9	0.19981	0.79644	0.10
mod8	Year + Percent.Grass + Year * Percent.Grass	5	286.7	2.0	0.19664	0.81243	0.08
mod5	Year + Roads	4	290.7	5.9	0.02741	0.83457	0.04
mod9	Year + Year * Percent.Grass + Year * Wells	7	290.9	6.2	0.02387	0.81142	0.07
mod6	Year + Roads + Year * Roads	5	292.8	8.1	0.00919	0.83455	0.03
mod1	Null	2	293.4	8.6	0.00709	0.86045	0.00
mod2	Year	3	294.4	9.6	0.00426	0.85635	0.00
mod3	Year + Wells	4	294.5	9.7	0.00408	0.84863	0.01
mod11	Year + Year * Roads + Year * Wells	7	295.5	10.8	0.00237	0.82802	0.03
mod4	Year + Wells + Year * Wells	5	296.6	11.9	0.00137	0.84859	0.00
Best landscape model plus site-specific models:							
mod12	Year + Percent.Grass + AvVOR	5	268.0	0.0	0.41321	0.74831	0.22
mod26	Year + Percent.Grass + Ltr.Depth	5	268.7	0.7	0.28948	0.75065	0.22
mod13	Year + Percent.Grass + AvVOR + Year * AvVOR	6	269.6	1.7	0.18095	0.74641	0.22
mod27	Year + Percent.Grass + Ltr.Depth + Year * Ltr.Depth	6	270.8	2.8	0.10255	0.75014	0.21
mod14	Year + Percent.Grass + Slope	5	276.8	8.8	0.00502	0.77782	0.16
mod24	Year + Percent.Grass + Percent.Litter	5	276.9	9.0	0.00463	0.77837	0.16
mod15	Year + Percent.Grass + Slope + Year * Slope	6	278.7	10.7	0.00195	0.77668	0.16
mod25	Year + Percent.Grass + Percent.Litter + Year * Percent.Litter	6	279.1	11.1	0.00158	0.77809	0.15
mod18	Year + Percent.Grass + Percent.AGCR	5	283.2	15.2	0.00020	0.79998	0.11
mod7	Year + Percent.Grass	4	284.8	16.8	0.00009	0.81324	0.09
mod20	Year + Percent.Grass + Percent.POPR	5	284.9	16.9	0.00009	0.80590	0.10
mod19	Year + Percent.Grass + Percent.AGCR + Year * Percent.AGCR	6	285.2	17.2	0.00008	0.79913	0.11
mod16	Year + Percent.Grass + FQI	5	286.1	18.2	0.00005	0.81037	0.09
mod22	Year + Percent.Grass + Percent.BG	5	286.1	18.2	0.00005	0.81041	0.09
mod21	Year + Percent.Grass + Percent.POPR + Year * Percent.POPR	6	286.9	18.9	0.00003	0.80504	0.09
mod23	Year + Percent.Grass + Percent.BG + Year * Percent.BG	6	288.1	20.1	0.00002	0.80929	0.08
mod17	Year + Percent.Grass + FQI + Year * FQI	6	288.4	20.4	0.00002	0.81037	0.08

¹ Number of parameters.

² Delta AIC (measure of each model relative to the best model).

³ Akaike weights (measure of the strength of evidence for each model).

⁴ Root mean square error.

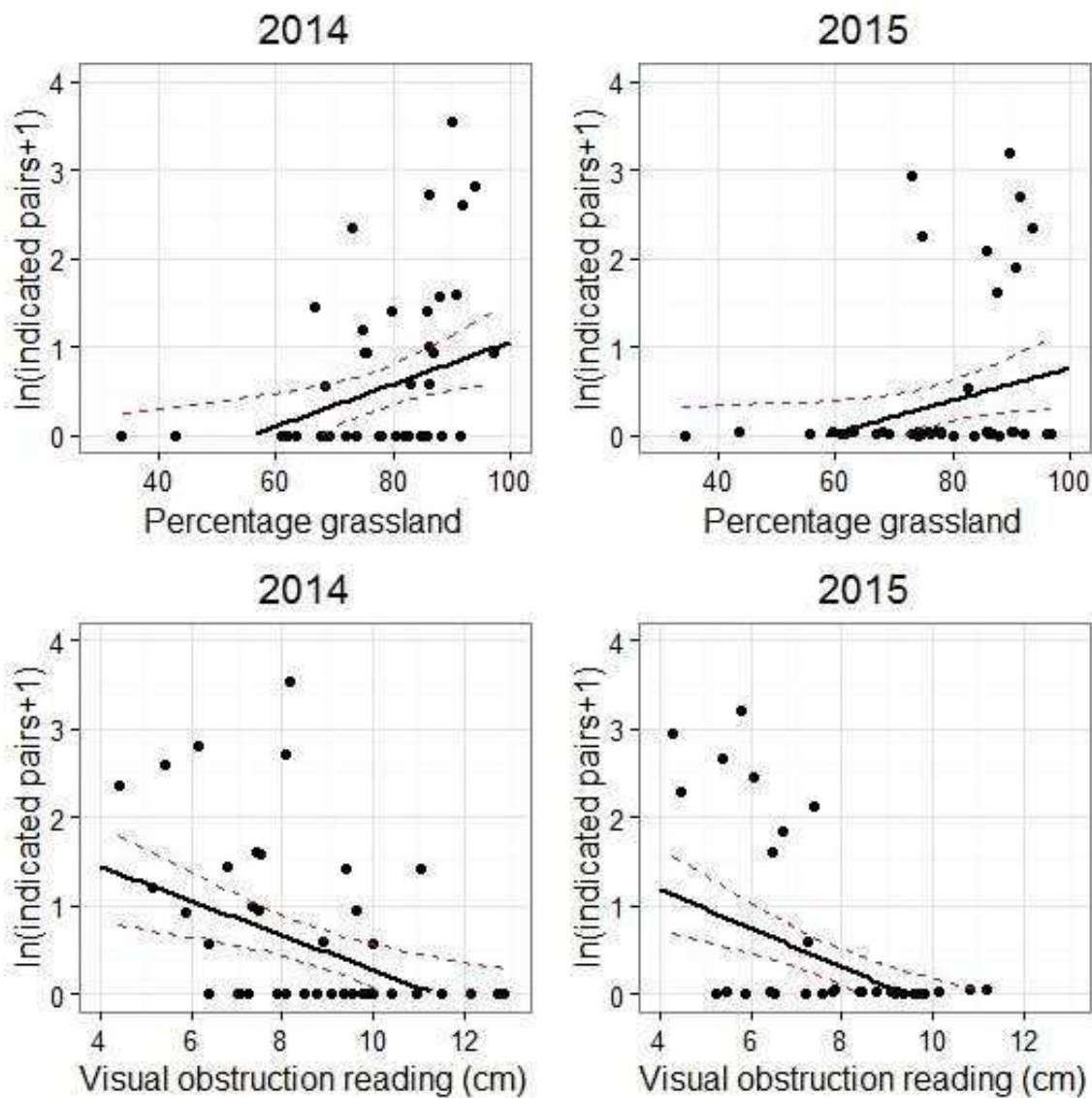


Figure 18. Model results showing relationship (black line with red-dashed 95% confidence intervals) between chestnut-collared longspur abundance and percentage grassland and visual obstruction reading.

Table 17. Model-selection results for models relating bobolink abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC_c). Variable definitions are given in Table 1.

Model		K ¹	AIC _c	Δ_i ²	ω_i ³	RMSE ⁴	Adj. R ²
Landscape models:							
mod1	Null	2	313.5	0.0	0.32075	0.93988	0.00
mod5	Year + Roads	4	315.0	1.5	0.15429	0.92843	0.01
mod2	Year	3	315.4	1.9	0.12176	0.93917	-0.01
mod3	Year + Wells	4	315.7	2.2	0.10865	0.93129	0.00
mod7	Year + Percent.Grass	4	315.9	2.4	0.09652	0.93225	0.00
mod6	Year + Roads + Year * Roads	5	317.1	3.7	0.05166	0.92842	0.00
mod8	Year + Percent.Grass + Year * Percent.Grass	5	317.3	3.8	0.04711	0.92918	0.00
mod4	Year + Wells + Year * Wells	5	317.8	4.4	0.03638	0.93128	-0.01
mod9	Year + Year * Percent.Grass + Year * Wells	7	318.2	4.7	0.03109	0.91434	0.01
mod11	Year + Year * Roads + Year * Wells	7	319.4	5.9	0.01676	0.91931	0.00
mod10	Year + Year * Percent.Grass + Year * Roads	7	319.6	6.1	0.01503	0.92019	0.00
Best landscape model plus site-specific models:							
mod14	Year + Slope	4	287.8	0.0	0.71700	0.82412	0.22
mod15	Year + Slope + Year * Slope	5	289.6	1.9	0.28265	0.82294	0.21
mod13	Year + AvVOR + Year * AvVOR	5	304.6	16.8	0.00016	0.87883	0.10
mod12	Year + AvVOR	4	305.2	17.4	0.00012	0.88958	0.09
mod26	Year + Ltr.Depth	4	307.7	19.9	0.00003	0.89934	0.07
mod27	Year + Ltr.Depth + Year * Ltr.Depth	5	308.0	20.3	0.00003	0.89208	0.07
mod20	Year + Percent.POPR	4	312.9	25.2	0.00000	0.92026	0.02
mod22	Year + Percent.BG	4	313.0	25.2	0.00000	0.92059	0.02
mod1	Null	2	313.5	25.7	0.00000	0.93988	0.00
mod16	Year + FQI	4	313.7	26.0	0.00000	0.92347	0.02
mod21	Year + Percent.POPR + Year * Percent.POPR	5	314.5	26.7	0.00000	0.91766	0.02
mod23	Year + Percent.BG + Year * Percent.BG	5	315.2	27.4	0.00000	0.92058	0.01
mod17	Year + FQI + Year * FQI	5	315.6	27.8	0.00000	0.92203	0.01
mod24	Year + Percent.Litter	4	316.2	28.4	0.00000	0.93346	0.00
mod18	Year + Percent.AGCR	4	317.2	29.4	0.00000	0.93756	-0.01
mod25	Year + Percent.Litter + Year * Percent.Litter	5	318.0	30.2	0.00000	0.93197	-0.01
mod19	Year + Percent.AGCR + Year * Percent.AGCR	5	318.4	30.6	0.00000	0.93337	-0.01

¹ Number of parameters.

² Delta AIC (measure of each model relative to the best model).

³ Akaike weights (measure of the strength of evidence for each model).

⁴ Root mean square error.

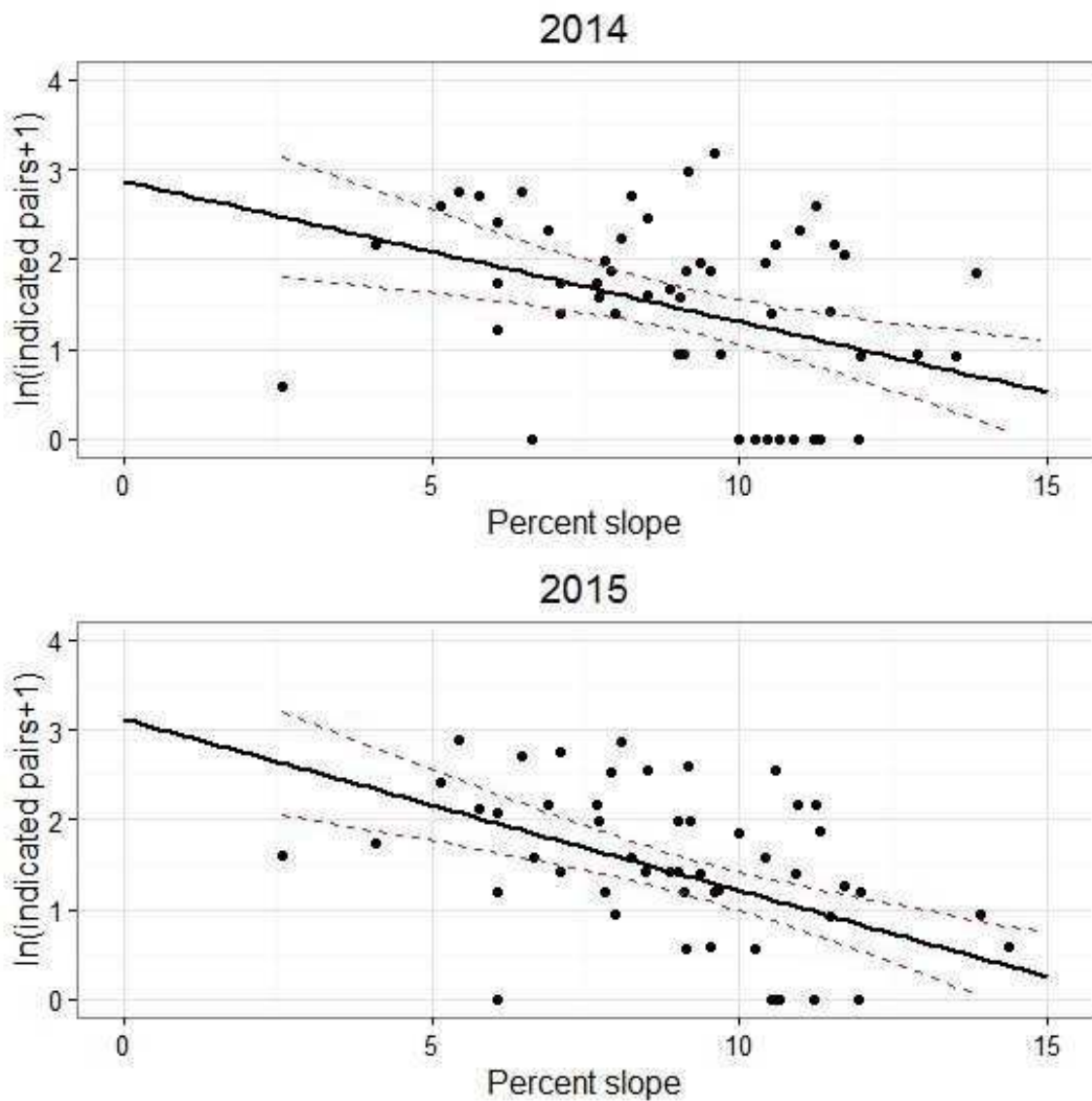


Figure 19. Model results showing relationship (black line with red-dashed 95% confidence intervals) between bobolink abundance and slope.

2.4.2.13. *Western meadowlark*

For the western meadowlark, the best supported and most parsimonious landscape model, based on Δ_i and ω_i , included Year, the interaction between Year and Roads, and the interaction between Year and Wells ($R^2 = 0.11$), indicating that western meadowlark abundance is weakly associated with the density of roads and wells within 1.6 km of the sample unit and that the strength of this association varied between the two years (Table 18). One site-specific variable (Percent.BG) improved the best-supported landscape model ($\omega_i = 0.54$, $R^2 = 0.18$). The best site-specific model included all of the interactions from the best landscape model but did not include interactions between the site-specific variable (Percent.BG) and Year, indicating that western meadowlark densities were associated with Percent.BG but the strength of the relationship did not vary with year. The final model explained 18% of the variation in western meadowlark abundance. Western meadowlark abundance increased with increasing road density in 2014 and 2015, but the relationship was stronger in 2014 (Fig. 19). Western meadowlark abundance increased slightly with an increase in bare ground in both years. Abundance declined in both years in relation to increasing well density (Fig. 20).

Table 18. Model-selection results for models relating western meadowlark abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC_c). Variable definitions are given in Table 1.

Model		K ¹	AIC _c	Δ_i ²	ω_i ³	RMSE ⁴	Adj. R ²
Landscape models:							
mod11	Year + Year * Roads + Year * Wells	7	146.0	0.0	0.48621	0.42968	0.11
mod3	Year + Wells	4	146.7	0.7	0.33783	0.44389	0.08
mod4	Year + Wells + Year * Wells	5	148.9	2.9	0.11489	0.44383	0.07
mod9	Year + Year * Percent.Grass + Year * Wells	7	152.6	6.6	0.01788	0.46671	0.00
mod1	Null	2	153.9	7.9	0.00937	0.45435	0.03
mod6	Year + Roads + Year * Roads	5	154.2	8.2	0.00796	0.44564	0.05
mod10	Year + Year * Percent.Grass + Year * Roads	7	154.3	8.3	0.00762	0.44231	0.06
mod5	Year + Roads	4	154.6	8.6	0.00669	0.45943	0.01
mod7	Year + Percent.Grass	4	154.8	8.8	0.00593	0.45991	0.01
mod2	Year	3	155.8	9.8	0.00361	0.46629	-0.01
mod8	Year + Percent.Grass + Year * Percent.Grass	5	157.0	11.0	0.00201	0.45987	0.00
Best landscape model plus site-specific models:							
mod22	Year + Year * Roads + Year * Wells + Percent.BG	8	137.9	0.0	0.54108	0.41047	0.18
mod23	Year + Year * Roads + Year * Wells + Percent.BG + Year * Percent.BG	9	139.5	1.6	0.23944	0.40916	0.18
mod16	Year + Year * Roads + Year * Wells + FQI	8	141.8	3.9	0.07603	0.41760	0.15
mod20	Year + Year * Roads + Year * Wells + Percent.POPR	8	143.5	5.6	0.03313	0.42065	0.14
mod18	Year + Year * Roads + Year * Wells + Percent.AGCR	8	143.5	5.6	0.03271	0.42070	0.14
mod17	Year + Year * Roads + Year * Wells + FQI + Year * FQI	9	144.1	6.2	0.02398	0.41750	0.15
mod21	Year + Year * Roads + Year * Wells + Percent.POPR + Year * Percent.POPR	9	145.6	7.7	0.01148	0.42021	0.14
mod19	Year + Year * Roads + Year * Wells + Percent.AGCR + Year * Percent.AGCR	9	145.6	7.8	0.01114	0.42032	0.14
mod11	Year + Year * Roads + Year * Wells	7	146.0	8.1	0.00936	0.42968	0.11
mod26	Year + Year * Roads + Year * Wells + Ltr.Depth	8	146.8	9.0	0.00616	0.42690	0.12
mod14	Year + Year * Roads + Year * Wells + Slope	8	147.7	9.8	0.00406	0.42847	0.11
mod12	Year + Year * Roads + Year * Wells + AvVOR	8	148.1	10.2	0.00326	0.42930	0.11
mod24	Year + Year * Roads + Year * Wells + Percent.Litter	8	148.3	10.4	0.00301	0.42960	0.11
mod27	Year + Year * Roads + Year * Wells + Ltr.Depth + Year * Ltr.Depth	9	149.1	11.2	0.00199	0.42672	0.11
mod15	Year + Year * Roads + Year * Wells + Slope + Year * Slope	9	150.0	12.1	0.00125	0.42847	0.10
mod13	Year + Year * Roads + Year * Wells + AvVOR + Year * AvVOR	9	150.4	12.6	0.00102	0.42924	0.10
mod25	Year + Year * Roads + Year * Wells + Percent.Litter + Year * Percent.Litter	9	150.6	12.7	0.00092	0.42960	0.10

¹ Number of parameters.

² Delta AIC (measure of each model relative to the best model).

³ Akaike weights (measure of the strength of evidence for each model).

⁴ Root mean square error.

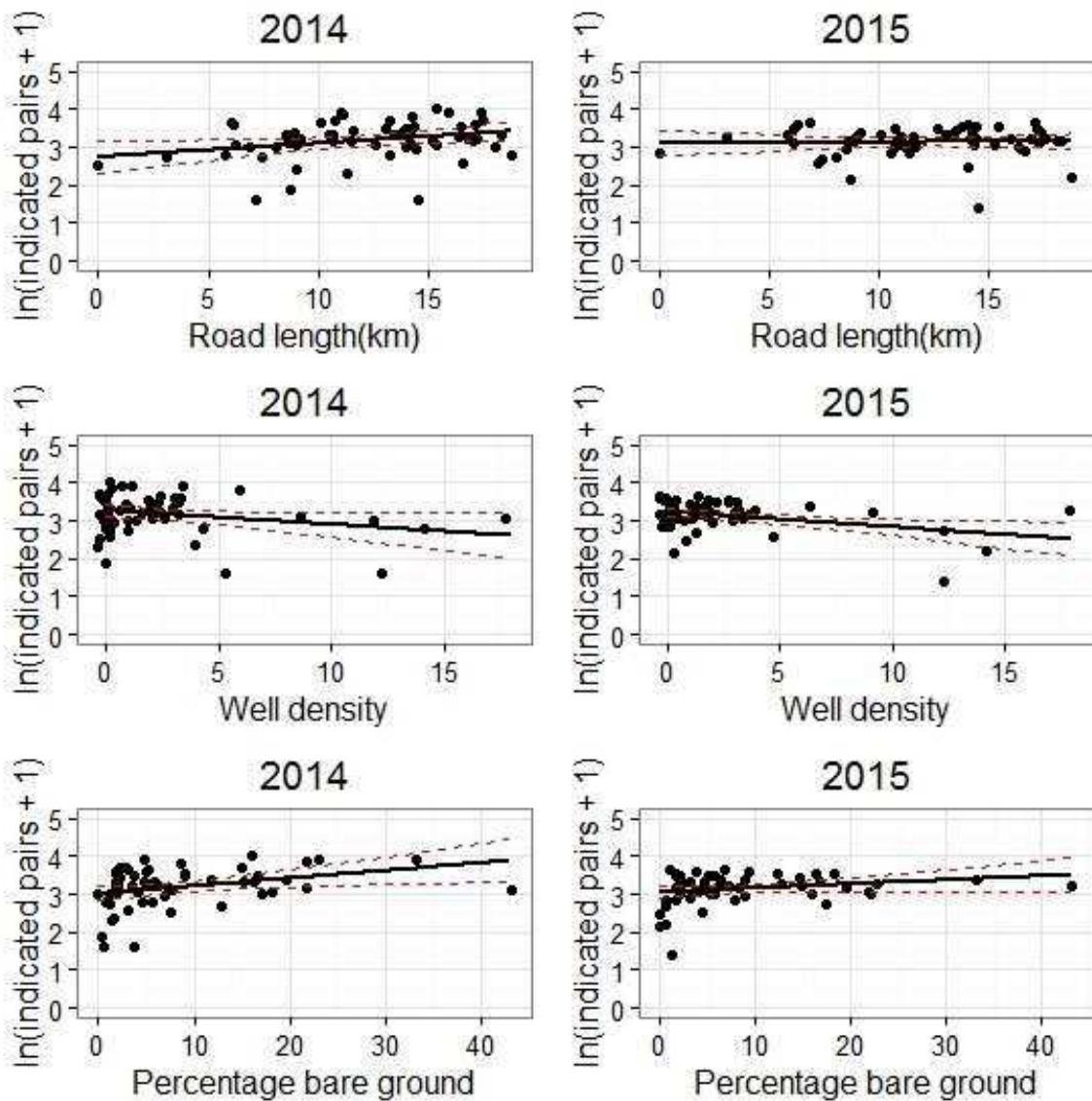


Figure 20. Model results showing relationship (black line with red-dashed 95% confidence intervals) between western meadowlark abundance and road length, well density, and percentage bare ground.

2.5. Discussion

Grassland bird diversity showed a decline with increasing grassland percentage within 1.6 km of the site edge and VOR. Biodiversity has been observed to decrease with an increasingly homogenous landscape (Benton et al., 2003; Fahrig et al., 2011). Although most of the 12 focal species are obligate grassland birds, several species are considered facultative grassland birds (e.g., Vickery et al., 1999), including clay-colored sparrow and field sparrow. These species tend to prefer grasslands with taller and denser vegetation, a shrubby vegetation component, or near a woody edge some edge (Dechant et al., 2002a, 2002b, 2002c), which may explain why overall grassland bird diversity decreased as grassland cover increased. Grassland birds also have different preferences for vegetation structure. For example, Madden and others (2000), found that Sprague's pipit used habitat with lower vegetation density (i.e., VOR) than habitats used by Bobolink. The presence of grasslands with high structural variability on the landscape increases habitat heterogeneity, which in turn increases biodiversity (Wiens, 1997). Since not all grassland birds have the same habitat requirements, it is important to manage for heterogeneity at broad spatial scales.

Grasshopper sparrow and western meadowlark were abundant and were ubiquitous (100-% frequency) on the LMNG, which made modeling habitat preferences for those two species especially difficult. Grasshopper sparrow abundance showed no associations with any of the plausible landscape models. In addition, abundances of two other common grassland birds, horned lark and bobolink, were not affected by any of the landscape variables. At the site-specific level, grasshopper sparrow abundance showed a negative, albeit weak, relationship with slope. Western meadowlark abundance changed only slightly across the gradient of well density and percentage bare ground. Western meadowlark abundance showed a positive relationship

with road length in the surrounding landscape in the first year of the study, but the relationship was weaker in the second year. This result may reflect the western meadowlark's attraction to fencelines along road rights-of-way, which provide an elevated song perch (Davis and Lanyon, 2008). These results are contrary to a recent study in Saskatchewan, Canada by Ludlow and others (2015), in which western meadowlarks tended to avoid nesting within 100 m of gravel roads. However, in that study, the proximity of roads did not influence the species' density. Our results supported another study on the LMNG where western meadowlark did not show any avoidance patterns to roads or single- and multi-bore well pads (Thompson et al., 2015).

About one-half of the 12 focal bird species in this study were associated with oil-related infrastructure (wells and roads), whereas the other species were largely unaffected. Other studies of oil and gas development have found similar variation in tolerance by grassland birds (Chalfoun et al., 2002; Francis et al., 2011; Kalyn Bogard and Davis, 2014). Kalyn Bogard and Davis (2014) suggested that inconsistencies among oil development studies can be attributed to variation in infrastructure age, spatial configuration of development, and drilling infrastructure presence (Gilbert and Chalfoun, 2011); chronic industrial noise (Blickley et al., 2012); landscape context (Hamilton et al., 2011); vehicular traffic (Ingelfinger and Anderson, 2004; Lawson et al., 2011); or regional variation in bird population density (Igl and Johnson, 1997; Winter et al., 2005).

Life-history characteristics of some species may explain at least some of the species-specific variations that we observed with oil development. For example, fences around oil-well pads and along access roads often exclude livestock from grazing strips of grassland around these structures, resulting in taller or denser vegetation and perch sites that may attract species like the clay-colored sparrow (Dechant et al., 2002b). Several studies have examined the effects

of energy development on prairie grouse, although much of the available research focuses on sage grouse (*Centrocercus urophasianus*) (Braun, 1986; Braun et al., 2002; Gilbert and Chalfoun, 2011). One study in North Dakota that focused on sharp-tailed grouse nest success reported that grouse nest success was higher in areas with intense oil and gas development because of a decrease in predator abundance (Burr, 2014). Another study in the LMNG found that sharp-tailed grouse did not appear to avoid areas with high oil well densities (Williamson, 2009). However, sharp-tailed grouse abundance was negatively associated with road density, which may be correlated with oil and gas development (Williamson, 2009). Our results indicate that sharp-tailed grouse abundance declined with increasing well density. In this study, we found that increased well densities had a positive effect on vesper sparrow abundance. Given that vesper sparrows exhibit an affinity for roads and that the species is typically more abundant along roads (Ownes and Myres, 1973; Sutter et al., 2000), this result was not unexpected. However, in Wyoming, Gilbert and Chalfoun (2011) showed that vesper sparrows were negatively affected by oil-well density.

In this study, the best plausible models for Sprague's pipit or Baird's sparrow abundance did not include well density, which is contrary to another study that found Sprague's pipit and Baird's sparrow abundance was negatively affected by oil development (Ludlow et al., 2015). However, increased oil well density may have indirect impacts on sensitive grassland birds via an increase in access roads in the area of oil development. We found that both of these sensitive species were negatively associated with road density. In two studies in grasslands of southern Alberta, Sprague's pipits did not appear to avoid low-traffic roads (Koper et al., 2009), and in Wyoming, sagebrush-obligate birds were significantly less common in areas within 100 m of roads associated with natural gas extraction (Ingelfinger and Anderson, 2004). It is likely that

roads associated with oil and natural gas extraction experience a considerably higher volume of vehicular traffic than traditional rural roads in comparable locations, and this is the case in our study area (Fershee, 2012). Reduced grassland bird density near roads is likely a direct result of heavy traffic associated with oil development in the region (Thompson et al., 2015). In lightly to moderately grazed native prairie in Saskatchewan, Sprague's pipit and Baird's sparrow were more abundant in grasslands alongside trails (i.e., single pair of wheel ruts) than in grasslands alongside roads (i.e., traveling surfaces with adjacent drainage ditches planted to exotic vegetation and ending with a fence 11-18 m from the traveling surface) (Sutter et al., 2000).

Given that many grassland birds are area sensitive and require large blocks of grassland during the breeding season (Johnson and Igl, 2001; Ribic et al., 2009), it is not surprising that several grassland birds in this region were associated with the percentage of grassland within the surrounding landscape. The negative relationship between clay-colored sparrow and field sparrow abundance with the percentage of grassland within 1.6 km of the study sites may be attributed to the species' habitat preferences for taller and denser grasslands or grasslands with a shrubby vegetation component (Dechant et al., 2002a, 2002b). Chestnut-collared longspurs and upland sandpiper responded positively to an increasing amount of grassland in the surrounding landscape. In another study in North Dakota, chestnut-collared longspurs tended to avoid areas with shrubby vegetation (Arnold and Higgins, 1986), and thus it is not surprising that this species would prefer a landscape with more grass coverage. Our results for the upland sandpiper are consistent with other studies, which recommended maintaining large, contiguous tracts of prairie to reduce habitat edge (Herkert, 1994; Klute, 1994).

The abundance of three species—Baird's sparrow, grasshopper sparrow, and bobolink—were negatively associated with slope. The effects of slope on grassland birds is not well known.

For example, the topography preferred by the Sprague's pipit is often listed in the literature (Environment Canada, 2011) and by experts (S. Davis, pers. Comm., Canadian Wildlife Service) as flat to gently (or slightly) rolling, although the thresholds for topography are generally unknown. Winter (2007) recommended that further research be done on the role of topography or slope on the distribution of sensitive grassland birds. Even within the narrow range of slopes evaluated in this study ($\leq 15\%$), we found that Baird's sparrow abundance declined as slope increased, which corresponds with Winter's findings on the Grand River National Grassland. Grasshopper sparrow abundance also declined with slope. Winter (2007) found that slope was highly correlated with the percentage of woody vegetation in her study areas. Baird's sparrows and other obligate grassland birds in this region may avoid steeper areas because of the increased amount of woody vegetation, which other studies have shown to negatively affect Baird's sparrow abundance (Lane, 1968; Winter, 1994; De Smet and Conrad, 1997). Slope did not occur in any of the best plausible models for the other nine grassland birds on this study.

Three of the focal bird species were associated with vegetation composition variables: clay-colored sparrow, field sparrow, and vesper sparrow. Clay-colored sparrow abundance increased as sites included more native plant species, whereas vesper sparrow abundance was higher on sites with fewer native plant species. For the clay-colored sparrow, our results are contrary to those from another study that found clay-colored sparrow abundance was negatively associated with native plant species (Prescott et al., 1995). In another North Dakota study, clay-colored sparrow abundance was positively associated with percentage forb cover (Schneider, 1998). On our sites, percentage forb cover was positively associated with FQI ($r = 0.48$), indicating that sites that had more native vegetation tended to have more forb cover. Wilson and Belcher (1989) also found that vesper sparrow abundance decreased with increasing cover of

native vegetation (Wilson and Belcher, 1989). However, other studies have found that vesper sparrow habitat preferences are fluid, and they will use both native and tame vegetation (Anstey et al., 1995; Prescott and Wagner, 1996; Sutter and Brigham, 1998). Field sparrow abundance showed a negative relationship with percentage cover of crested wheatgrass at the site level. However, the range of crested wheatgrass cover (0-25%) for this study made it difficult to draw inferences about field sparrow abundance in relation to crested wheatgrass cover.

It was not surprising that several grassland bird species were associated with structural vegetation variables, since many studies have shown that grassland birds tend to select grassland habitats based on vegetation structure rather than composition (Davis and Brittingham, 2004; Winter, 2007). The association between sharp-tailed grouse abundance and litter depth varied between years, suggesting that the association is weak. Horned lark abundance was negatively associated litter depth. This result was somewhat expected as horned larks prefer areas with short, sparse coverage of herbaceous vegetation (Davis et al., 1999). Upland sandpiper and western meadowlark abundance were positively associated with the percentage of bare ground cover at the site level. Fuhlendorf and others (2006) found upland sandpipers were more abundant in grassland patches that had been recently disturbed, and thus had minimal litter and more bare ground. Kantrud and Kologiski (1982) found that western meadowlark abundance was highest on sites that had an average of 17-25% bare ground. However, one study in Oregon reported that western meadowlarks were negatively associated with percentage bare ground (Wiens and Rotenberry, 1981). Both the Sprague's pipit and chestnut-collared longspur were less abundant as vegetation density (VOR) increased. In North Dakota, Madden and others (2000) found that Sprague's pipit occurrence was best predicted by VOR, and that pipit

abundance declined quickly as VOR increased. Also in North Dakota, Schneider (1998) reported that chestnut-collared longspur abundance was negatively associated with VOR.

2.6. Management implications

Livestock grazing has been shown to greatly influence the vegetation structure of grasslands (Wiens and Dyer, 1975; Ryder, 1980). Habitat structure is the main driver of grassland bird habitat selection (Fisher and Davis, 2010) and therefore it is important to manage livestock grazing intensity to provide structural diversity for grassland birds at both ends of the structure gradient (e.g., Fuhlendorf et al., 2006, Saab et al., 1995). The Dakota Prairie Grasslands developed a land and resource management plan (LRMP) in August 2007 (Svingen, 2009). The LRMP contained extensive direction on providing habitat for multiple species by setting vegetation structure goals for the entire LMNG. Three structure categories were set using their autumn VOR monitoring: low structure (i.e., ≤ 3.81 cm), moderate structure (i.e., 3.82-8.8 cm), and high structure (i.e., ≥ 8.9). Our results show that Sprague's pipit and chestnut-collared longspur abundance decreased on sites with a higher average VOR. These results highlight the importance of maintaining lower VOR's for some species through management tools, such as grazing. We recommend that land managers use differing grazing intensities to maintain habitat for the suite of grassland birds that breed in the LMNG. More specifically, areas with lower VOR should be maintained using higher stocking rates or specific grazing practices to maintain habitat for the sensitive species, such as the Sprague's pipit.

Baird's sparrow abundance was not associated with any of the structural vegetation measurements, however, Baird's sparrow abundance was negatively associated with areas that had higher percent slope. Although we cannot reasonably expect land managers to alter

topography (i.e., slope), managers can focus their management for species—Bobolink, grasshopper sparrow, and Baird’s sparrow—that prefer flatter topography.

In this study, the two grassland birds—Sprague’s pipit and Baird’s sparrow—considered to be “sensitive” by the USFS were negatively associated with road density. The recent oil development in western North Dakota overlaps considerably with the breeding ranges of sensitive grassland birds and impacts federally-owned grasslands that are important breeding areas for these species. Our results suggest that the access roads built to well pads may negatively affect sensitive grassland birds. When possible, we recommend that access roads be kept to a minimum by strategically placing well pads close together or using multi-bore well pads (*sensu* Thompson et al., 2015).

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APPENDIX

Table A1. Legal land description (Township, Range, Section and Quarter) and area (ha) of 60 study sites in the McKenzie District of the Little Missouri National Grassland in western North Dakota, 2014 and 2015.

Site ID	Legal Description ¹	Quarter	Area	Site ID	Legal Description	Quarter	Area	Site ID	Legal Description	Quarter	Area
1	149 103 14	SW1/4	159.4	21	145 104 18	NE1/4	159.6	41	146 104 34	SW1/4	159.5
2	148 099 04	NW1/4	151.8	22	145 104 35	NE1/4	159.0	42	146 104 25	NE1/4	159.2
3	146 105 23	SE1/4	159.4	23	145 104 35	NW1/4	159.0	43	146 105 25	NE1/4	160.4
4	146 103 22	SW1/4	160.1	24	149 103 25	NW1/4	156.5	44	150 103 15	SE1/4	159.1
5	145 098 33	SW1/4	155.4	25	148 100 30	SE1/4	143.7	45	150 103 15	SW1/4	159.9
6	148 103 10	SW1/4	159.2	26	148 100 15	NE1/4	161.7	46	147 101 17	SE1/4	159.7
7	148 103 27	NW1/4	160.8	27	145 100 02	SE1/4	159.1	47	146 104 30	NW1/4	156.8
8	149 103 03	SW1/4	158.7	28	148 100 15	SW1/4	159.7	48	147 105 24	NE1/4	159.9
9	149 103 03	SE1/4	158.7	29	145 104 14	NE1/4	157.7	49	149 104 33	NW1/4	154.5
10	148 103 34	NW1/4	158.7	30	145 104 14	NW1/4	158.3	50	153 096 12	SE1/4	158.7
11	148 103 15	NW1/4	160.9	31	145 104 33	NE1/4	157.9	51	149 104 33	SW1/4	160.4
12	148 103 22	SW1/4	156.7	32	148 100 31	NW1/4	143.1	52	147 104 22	SW1/4	159.0
13	152 097 10	NE1/4	156.6	33	148 100 11	SW1/4	159.0	53	145 103 31	NE1/4	157.9
14	146 105 11	NE1/4	159.4	34	145 098 09	SE1/4	162.4	54	148 102 15	NW1/4	160.4
15	149 103 23	SE1/4	159.1	35	147 104 34	SW1/4	159.8	55	147 104 21	NW1/4	160.2
16	152 097 29	NE1/4	159.0	36	145 098 03	NW1/4	157.3	56	148 105 35	SW1/4	159.6
17	145 105 24	SE1/4	159.3	37	153 094 23	SW1/4	157.1	57	152 097 04	SW1/4	191.7
18	145 105 11	SW1/4	158.8	38	146 105 25	SW1/4	161.8	58	148 104 22	NW1/4	158.9
19	149 103 02	SW1/4	159.5	39	147 103 31	SE1/4	144.4	59	148 104 27	SW1/4	158.4
20	145 104 32	NW1/4	160.3	40	146 104 15	NW1/4	159.5	60	145 104 12	SE1/4	159.6

¹ Legal description includes Township Range, and Section.

Table A2. Densities (breeding pairs / 100 ha) averaged across years of 82 bird species observed during surveys conducted on the Little Missouri National Grassland between 23 May to 25 July 2014 and 19 May to 17 July 2015. The species are in taxonomic order.

Scientific name	Common name	Alpha code	Average densities (pairs per 100 ha)
<i>Cathartes aura</i>	Turkey vulture	TUVU	0.047
<i>Anas strepera</i>	Gadwall	GADW	0.007
<i>Anas americana</i>	American wigeon	AMWI	0.013
<i>Anas platyrhynchos</i>	Mallard	MALL	0.053
<i>Anas discors</i>	Blue-winged teal	BWTE	0.026
<i>Aythya valisineria</i>	Canvasback	CANV	0.052
<i>Circus cyaneus</i>	Northern harrier	NOHA	0.157
<i>Buteo swainsoni</i>	Swainson's hawk	SWHA	0.113
<i>Buteo jamaicensis</i>	Red-tailed hawk	RTHA	0.072
<i>Aquila chrysaetos</i>	Golden eagle	GOEA	0.013
<i>Falco sparverius</i>	American kestrel	AMKE	0.230
<i>Falco mexicanus</i>	Prairie falcon	PRFA	0.007
<i>Perdix perdix</i>	Gray partridge	GRPA	0.007
<i>Phasianus colchicus</i>	Ring-necked pheasant	RPHE	0.217
<i>Tympanuchus phasianellus</i>	Sharp-tailed grouse	STGR	1.701
<i>Meleagris gallopavo</i>	Wild turkey	WITU	0.040
<i>Charadrius vociferus</i>	Killdeer	KILL	0.375
<i>Bartramia longicauda</i>	Upland sandpiper	UPSA	1.228
<i>Limosa fedoa</i>	Marbled godwit	MAGO	0.013
<i>Gallinago delicata</i>	Wilson's snipe	WISN	0.026
<i>Columba livia</i>	Rock dove	RODO	0.099
<i>Zenaida macroura</i>	Mourning dove	MODO	2.276
<i>Bubo Virginianus</i>	Great horned owl	GHOW	0.013
<i>Athene cunicularia</i>	Burrowing owl	BUOW	0.027
<i>Asio flammeus</i>	Short-eared owl	SEOW	0.014
<i>Chordeiles minor</i>	Common nighthawk	CONI	0.293
<i>Colaptes auratus</i>	Northern flicker	NOFL	0.641
<i>Empidonax trailii</i>	Willow flycatcher	WIFL	0.005
<i>Empidonax minimus</i>	Least flycatcher	LEFL	0.236
<i>Sayornis saya</i>	Say's phoebe	SAPH	0.046
<i>Tyrannus verticalis</i>	Western kingbird	WEKI	0.300
<i>Tyrannus tyrannus</i>	Eastern kingbird	EAKI	2.177
<i>Lanius ludovicianus</i>	Loggerhead shrike	LOSH	0.196
<i>Vireo gilvus</i>	Warbling vireo	WAVI	0.006
<i>Cyanocitta cristata</i>	Blue jay	BLJA	0.006

Table A2. Densities (breeding pairs / 100 ha) averaged across years of 82 bird species observed during surveys conducted on the Little Missouri National Grassland between 23 May to 25 July 2014 and 19 May to 17 July 2015 (continued). The species are in taxonomic order.

Scientific name	Common name	Alpha code	Average densities (pairs per 100 ha)
<i>Pica pica</i>	Black-billed magpie	BBMA	0.276
<i>Corvus brachyrhynchos</i>	American crow	AMCR	0.133
<i>Eremophila alpestris</i>	Horned lark	HOLA	1.848
<i>Tachycineta bicolor</i>	Tree swallow	TRES	0.111
<i>Riparia riparia</i>	Bank swallow	BANS	0.006
<i>Petrochelidon pyrrhonota</i>	Cliff swallow	CLSW	0.014
<i>Hirundo rustica</i>	Barn swallow	BARS	0.274
<i>Poecile atricapillus</i>	Black-capped chickadee	BCCH	0.013
<i>Salpinctes obsoletus</i>	Rock wren	ROWR	0.065
<i>Troglodytes aedon</i>	House wren	HOWR	0.984
<i>Sialia sialis</i>	Eastern bluebird	EABL	0.014
<i>Sialia currucoides</i>	Mountain bluebird	MOBL	0.034
<i>Turdus migratorius</i>	American robin	AMRO	0.334
<i>Dumetella carolinensis</i>	Gray catbird	GRCA	0.566
<i>Toxostoma rufum</i>	Brown thrasher	BRTH	0.791
<i>Sturnus vulgaris</i>	European starling	EUST	0.020
<i>Anthus spragueii</i>	Sprague's pipit	SPPI	1.606
<i>Bombycilla cedrorum</i>	Cedar waxwing	CEDW	0.148
<i>Setophaga petechia</i>	Yellow warbler	YWAR	2.544
<i>Geothlypis trichas</i>	Common yellowthroat	COYE	0.452
<i>Icteria virens</i>	Yellow-breasted chat	YBCH	0.279
<i>Pipilo maculatus</i>	Spotted towhee	SPTO	2.339
<i>Spizella passerina</i>	Chipping sparrow	CHSP	0.013
<i>Spizella pallida</i>	Clay-colored sparrow	CCSP	3.321
<i>Spizella pusilla</i>	Field sparrow	FISP	2.270
<i>Poocetes gramineus</i>	Vesper sparrow	VESP	6.805
<i>Chondestes grammacus</i>	Lark sparrow	LASP	0.351
<i>Calamospiza melanocorys</i>	Lark bunting	LARB	0.010
<i>Passerculus sandwichensis</i>	Savannah sparrow	SAVS	0.759
<i>Ammodramus savannarum</i>	Grasshopper sparrow	GRSP	30.924
<i>Ammodramus bairdii</i>	Baird's sparrow	BAIS	1.307
<i>Melospiza melodia</i>	Song sparrow	SOSP	0.013
<i>Calcarius ornatus</i>	Chestnut-collared longspur	CCLO	1.665
<i>Pheucticus melanocephalus</i>	Black-headed grosbeak	BHGR	0.013
<i>Passerina amoena</i>	Lazuli bunting	LAZB	0.053

Table A2. Densities (breeding pairs / 100 ha) averaged across years of 82 bird species observed during surveys conducted on the Little Missouri National Grassland between 23 May to 25 July 2014 and 19 May to 17 July 2015 (continued). The species are in taxonomic order.

Scientific name	Common name	Alpha code	Average densities (pairs per 100 ha)
<i>Spiza americana</i>	Dickcissel	DICK	0.020
<i>Dolichonyx oryzivorus</i>	Bobolink	BOBO	4.224
<i>Agelaius phoeniceus</i>	Red-winged blackbird	RWBL	0.942
<i>Sturnella neglecta</i>	Western meadowlark	WEME	22.529
<i>Xanthocephalus xanthocephalus</i>	Yellow-headed blackbird	YHBL	0.003
<i>Euphagus cyanocephalus</i>	Brewer's blackbird	BRBL	0.567
<i>Quiscalus quiscula</i>	Common grackle	COGR	0.152
<i>Molothrus ater</i>	Brown-headed cowbird	BHCO	1.826
<i>Icterus spurius</i>	Orchard oriole	OROR	0.033
<i>Icterus galbula</i>	Baltimore oriole	BAOR	0.013
<i>Icterus bullockii</i>	Bullock's oriole	BUOR	0.019
<i>Spinus tristis</i>	American goldfinch	AMGO	0.492

Table A3. Plant species observed on 171 modified Whittaker plots on 57 study sites in the Little Missouri National Grassland, 2014 and 2015. Floristic composition was measured only once in the two field seasons, one-half of the study sites in the first year and one-half during the second year. Non-native species are not assigned a C value. The species are in alphabetical order.

Scientific name	Common name	C ¹	Origin	Physiognomy
<i>Achillea millefolium</i> subsp. <i>lanulosa</i>	Yarrow	3	Native	FORB
<i>Agoseris glauca</i>	False dandelion	8	Native	FORB
<i>Agropyron caninum</i> subsp. <i>subsecundus</i>	N/A	6	Native	GRASS
<i>Agropyron caninum</i> subsp. <i>trachycaulus</i>	Slender wheatgrass	6	Native	GRASS
<i>Agropyron cristatum</i>	Crested wheatgrass	*	Introduced	GRASS
<i>Agrostis hyemalis</i>	Ticklegrass	1	Native	GRASS
<i>Allium textile</i>	White wild onion	7	Native	FORB
<i>Ambrosia psilostachya</i>	Western ragweed	2	Native	FORB
<i>Amorpha canescens</i>	Lead plant	9	Native	SHRUB
<i>Andropogon gerardii</i>	Big bluestem	5	Native	GRASS
<i>Andropogon hallii</i>	Sand bluestem	5	Native	GRASS
<i>Androsace occidentalis</i>	Western rock jasmine	5	Native	FORB
<i>Andropogon scoparius</i>	Little bluestem	6	Native	GRASS
<i>Anemone canadensis</i>	Meadow anemone	4	Native	FORB
<i>Anemone cylindrica</i>	Candle anemone	7	Native	FORB
<i>Anemone patens</i>	Pasque flower	9	Native	FORB
<i>Antennaria neglecta</i>	Field pussy-toes	5	Native	FORB
<i>Arabis hirsuta</i> var. <i>pyncocarpa</i>	Rock cress	7	Native	FORB
<i>Arabis holboellii</i> var. <i>collinsii</i>	Rock cress	5	Native	FORB
<i>Aristida purpurea</i> var. <i>robusta</i>	Red three-awn	4	Native	GRASS
<i>Arnica fulgens</i>	Arnica	10	Native	FORB
<i>Artemisia cana</i>	Dwarf sagebrush	7	Native	SHRUB
<i>Artemisia dracunculus</i>	Silky wormwood	4	Native	FORB
<i>Artemisia frigida</i>	Prairie sagewort	4	Native	SHRUB
<i>Artemisia ludoviciana</i> var. <i>ludoviciana</i>	White sage	3	Native	FORB
<i>Asclepias verticillata</i>	Whorled milkweed	3	Native	FORB
<i>Asclepias viridiflora</i>	Green milkweed	8	Native	FORB

¹ Coefficients of conservatism (C values) developed for North and South Dakota.

Table A3. Plant species observed on 171 modified Whittaker plots on 57 study sites in the Little Missouri National Grassland, 2014 and 2015. Floristic composition was measured only once in the two field seasons, one-half of the study sites in the first year and one-half during the second year. Non-native species are not assigned a C value (continued). The species are in alphabetical order.

Scientific name	Common name	C ¹	Origin	Physiognomy
<i>Astragalus adsurgens</i> var. <i>robustior</i>	Standing milk-vetch	8	Native	FORB
<i>Astragalus agrestis</i>	Field milk-vetch	6	Native	FORB
<i>Astragalus crassicaarpus</i> var. <i>crassicaarpus</i>	Ground-plum	7	Native	FORB
<i>Astragalus flexuosus</i>	Pliant milk-vetch	4	Native	FORB
<i>Astragalus gilviflorus</i>	Plains orophaca	7	Native	FORB
<i>Astragalus gracilis</i>	Slender milk-vetch	8	Native	FORB
<i>Astragalus lotiflorus</i>	Lotus milk-vetch	6	Native	FORB
<i>Aster oblongifolius</i>	Aromatic aster	8	Native	FORB
<i>Astragalus tenellus</i>	Pulse milk-vetch	8	Native	FORB
<i>Atriplex nuttallii</i>	Moundscale	6	Native	SHRUB
<i>Bouteloua curtipendula</i>	Sideoats grama	5	Native	GRASS
<i>Bouteloua gracilis</i>	Blue grama	7	Native	GRASS
<i>Bromus inermis</i>	Smooth brome	*	Introduced	GRASS
<i>Bromus japonicus</i>	Japanese brome	*	Introduced	GRASS
<i>Bromus squarrosus</i>	Nodding brome	*	Introduced	GRASS
<i>Buchloe dactyloides</i>	Buffalo grass	4	Native	GRASS
<i>Calamovilfa longifolia</i>	Prairie sandreed	5	Native	GRASS
<i>Calylophus serrulatus</i>	Plains yellow primrose	7	Native	FORB
<i>Camelina microcarpa</i>	Small-seeded false flax	*	Introduced	FORB
<i>Campanula rotundifolia</i>	Harebell	7	Native	FORB
<i>Cerastium arvense</i>	Prairie chickweed	2	Native	FORB
<i>Cerastium brachypodum</i>	N/A	1	Native	FORB
<i>Ceratoides lanata</i>	White sage, Winter fat	8	Native	SHRUB
<i>Chenopodium album</i>	Lamb's quarters	*	Introduced	FORB
<i>Chrysothamnus nauseosus</i> subsp. <i>nauseosus</i>	Rabbit brush	4	Native	SHRUB
<i>Chrysopsis villosa</i> var. <i>villosa</i>	Golden aster	3	Native	FORB
<i>Cirsium arvense</i>	Canada thistle, Field thistle	*	Introduced	FORB

¹ Coefficients of conservatism (C values) developed for North and South Dakota.

Table A3. Plant species observed on 171 modified Whittaker plots on 57 study sites in the Little Missouri National Grassland, 2014 and 2015. Floristic composition was measured only once in the two field seasons, one-half of the study sites in the first year and one-half during the second year. Non-native species are not assigned a C value (continued). The species are in alphabetical order.

Scientific name	Common name	C ¹	Origin	Physiognomy
<i>Cirsium flodmanii</i>	Flodman's thistle	5	Native	FORB
<i>Cirsium undulatum</i>	Wavy-leaf thistle	7	Native	FORB
<i>Cirsium vulgare</i>	Bull thistle	*	Introduced	FORB
<i>Collomia linearis</i>	Collomia	5	Native	FORB
<i>Comandra umbellata</i>	N/A	8	Native	FORB
<i>Convolvulus arvensis</i>	Field bindweed	*	Introduced	FORB
<i>Conyza canadensis</i>	Horseweed	0	Native	FORB
<i>Conyza ramosissima</i>	Spreading fleabane	0	Native	FORB
<i>Coryphantha vivipara</i>	Pincushion cactus	10	Native	FORB
<i>Carex brevior</i>	Fescue sedge	4	Native	SEDGE
<i>Carex eleocharis</i>	Needleleaf sedge	4	Native	SEDGE
<i>Carex filifolia</i>	Thread-leaved sedge	7	Native	SEDGE
<i>Carex heliophila</i>	N/A	7	Native	SEDGE
<i>Carex prairea</i>	N/A	10	Native	SEDGE
<i>Dalea candida</i> var. <i>candida</i>	White prairie-clover	8	Native	FORB
<i>Dalea purpurea</i> var. <i>purpurea</i>	Purple prairie clover	8	Native	FORB
<i>Descurainia sophia</i>	Flixweed	*	Introduced	FORB
<i>Dichanthelium wilcoxianum</i>	Wilcox dichanthelium	8	Native	GRASS
<i>Distichlis spicata</i> var. <i>stricta</i>	Inland saltgrass	2	Native	GRASS
<i>Echinacea angustifolia</i>	Purple coneflower	7	Native	FORB
<i>Echinochloa crusgalli</i>	Barnyard grass	*	Introduced	GRASS
<i>Elymus repens</i>	Quackgrass	*	Introduced	GRASS
<i>Equisetum laevigatum</i>	Smooth scouring rush	3	Native	FERN
<i>Erigeron annuus</i>	Annual fleabane	3	Native	FORB
<i>Eriogonum flavum</i>	Yellow wild buckwheat	7	Native	FORB
<i>Eriogonum pauciflorum</i> var. <i>pauciflorum</i>	N/A	5	Native	FORB
<i>Erigeron strigosus</i>	Daisy fleabane	3	Native	FORB

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Table A3. Plant species observed on 171 modified Whittaker plots on 57 study sites in the Little Missouri National Grassland, 2014 and 2015. Floristic composition was measured only once in the two field seasons, one-half of the study sites in the first year and one-half during the second year. Non-native species are not assigned a C value (continued). The species are in alphabetical order.

Scientific name	Common name	C ¹	Origin	Physiognomy
<i>Erucastrum gallicum</i>	Dog mustard	*	Introduced	FORB
<i>Erysimum asperum</i>	Western wallflower	3	Native	FORB
<i>Erysimum inconspicuum</i>	Smallflower wallflower	7	Native	FORB
<i>Euphorbia glyptosperma</i>	Ridge-seeded spurge	0	Native	FORB
<i>Euphorbia spathulata</i>	N/A	5	Native	FORB
<i>Festuca octoflora</i>	Sixweeks fescue	0	Native	GRASS
<i>Festuca scabrella</i>	Rough fescue	8	Native	GRASS
<i>Fraxinus pennsylvanica</i>	Red ash, Green ash	5	Native	TREE
<i>Gaillardia aristata</i>	Blanket flower	5	Native	FORB
<i>Galium aparine</i>	Catchweed bedstraw	0	Native	FORB
<i>Galium boreale</i>	Northern bedstraw	4	Native	FORB
<i>Gaura coccinea</i>	Scarlet gaura	4	Native	FORB
<i>Geum triflorum</i>	Torch flower, Maidenhair	8	Native	FORB
<i>Glycyrrhiza lepidota</i>	Wild licorice	2	Native	FORB
<i>Gnaphalium palustre</i>	Diffuse cudweed	3	Native	FORB
<i>Grindelia squarrosa</i> var. <i>quasiperennis</i>	Curly-top gumweed	1	Native	FORB
<i>Gutierrezia sarothrae</i>	Snakeweed	6	Native	SHRUB
<i>Haplopappus spinulosus</i>	Cutleaf ironplant	7	Native	FORB
<i>Hedeoma hispidum</i>	Rough false pennyroyal	2	Native	FORB
<i>Helictotrichon hookeri</i>	Spike oat	9	Native	GRASS
<i>Helianthus maximilianii</i>	Maximilian sunflower	5	Native	FORB
<i>Helianthus rigidus</i> subsp. <i>subrhomboideus</i>	Stiff sunflower	8	Native	FORB
<i>Hesperostipa comata</i>	Needle-and-thread	6	Native	GRASS
<i>Hesperostipa spartea</i>	Porcupine-grass	8	Native	GRASS
<i>Heuchera richardsonii</i>	Alumroot	8	Native	FORB
<i>Hordeum jubatum</i>	Foxtail barley	0	Native	GRASS
<i>Hymenoxys acaulis</i>	Stemless hymenoxys	6	Native	FORB

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Table A3. Plant species observed on 171 modified Whittaker plots on 57 study sites in the Little Missouri National Grassland, 2014 and 2015. Floristic composition was measured only once in the two field seasons, one-half of the study sites in the first year and one-half during the second year. Non-native species are not assigned a C value (continued). The species are in alphabetical order.

Scientific name	Common name	C ¹	Origin	Physiognomy
<i>Hymenopappus tenuifolius</i>	Slimleaf hymenopappus	8	Native	FORB
<i>Juniperus communis</i>	Dwarf juniper	5	Native	SHRUB
<i>Juniperus horizontalis</i>	Creeping Juniper	6	Native	SHRUB
<i>Juncus interior</i>	Inland rush	5	Native	FORB
<i>Juniperus scopulorum</i>	Rocky mountain juniper	4	Native	TREE
<i>Juniperus virginiana</i>	Red cedar	0	Native	TREE
<i>Kochia scoparia</i>	Kochia, Fire-weed	*	Introduced	FORB
<i>Koeleria pyramidata</i>	Junegrass	7	Native	GRASS
<i>Lactuca oblongifolia</i>	Blue lettuce	1	Native	FORB
<i>Lepidium densiflorum</i>	Peppergrass	0	Native	FORB
<i>Liatris punctata</i>	Blazing star	7	Native	FORB
<i>Lilium philadelphicum</i>	Wild lily	8	Native	FORB
<i>Linum perenne</i> var. <i>lewisii</i>	Blue flax	6	Native	FORB
<i>Linum rigidum</i> var. <i>rigidum</i>	Stiffstemflax	5	Native	FORB
<i>Lithospermum incisum</i>	Narrow-leaved puccoon	7	Native	FORB
<i>Lotus purshianus</i>	Prairie trefoil, Deer vetch	3	Native	FORB
<i>Lygodesmia juncea</i>	Skeletonweed	2	Native	FORB
<i>Medicago lupulina</i>	Black medick	*	Introduced	FORB
<i>Medicago sativa</i>	Alfalfa	*	Introduced	FORB
<i>Melilotus alba</i>	White sweet clover	*	Introduced	FORB
<i>Melilotus officinalis</i>	Yellow sweet clover	*	Introduced	FORB
<i>Mirabilis linearis</i>	Narrowleaf four-o'clock	7	Native	FORB
<i>Monarda fistulosa</i> var. <i>fistulosa</i>	Wild bergamot	5	Native	FORB
<i>Muhlenbergia cuspidata</i>	Plains muhly	8	Native	GRASS
<i>Nassella viridula</i>	Green needlegrass	5	Native	GRASS
<i>Oenothera albicaulis</i>	Prairie evening primrose	5	Native	FORB
<i>Oenothera biennis</i>	Common evening primrose	0	Native	FORB

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Table A3. Plant species observed on 171 modified Whittaker plots on 57 study sites in the Little Missouri National Grassland, 2014 and 2015. Floristic composition was measured only once in the two field seasons, one-half of the study sites in the first year and one-half during the second year. Non-native species are not assigned a C value (continued). The species are in alphabetical order.

Scientific name	Common name	C ¹	Origin	Physiognomy
<i>Oenothera nuttallii</i>	White-stemmed evening primrose	8	Native	FORB
<i>Opuntia fragilis</i>	Little prickly pear	5	Native	SHRUB
<i>Opuntia polyacantha</i>	Plains prickly pear	3	Native	SHRUB
<i>Orthocarpus luteus</i>	Owl clover	6	Native	FORB
<i>Oxalis stricta</i>	Yellow wood sorrel	0	Native	FORB
<i>Oxytropis lambertii</i>	Purple locoweed	5	Native	FORB
<i>Pascopyron smithii</i>	Western wheatgrass	4	Native	GRASS
<i>Penstemon gracilis</i>	Slender beardtongue	6	Native	FORB
<i>Phlox hoodii</i>	Hood's phlox	6	Native	FORB
<i>Plantago eriopoda</i>	Alkali plantain	5	Native	FORB
<i>Plantago patagonica</i>	Patagonian plantain	1	Native	FORB
<i>Poa compressa</i>	Canada bluegrass	*	Introduced	GRASS
<i>Poa palustris</i>	Fowl bluegrass	4	Native	GRASS
<i>Poa pratensis</i>	Kentucky bluegrass	*	Introduced	GRASS
<i>Poa sandbergii</i>	Sandberg's bluegrass	8	Native	GRASS
<i>Potentilla gracilis</i>	Cinquefoil	5	Native	FORB
<i>Polygala alba</i>	White milkwort	5	Native	FORB
<i>Polygonum convolvulus</i>	Wild buckwheat	*	Introduced	FORB
<i>Polygonum erectum</i>	Erect knotweed	0	Native	FORB
<i>Polygonum ramosissimum</i>	Bushy knotweed	3	Native	FORB
<i>Polygala verticillata</i>	Whorled milkwort	8	Native	FORB
<i>Potentilla arguta</i>	Tall cinquefoil	8	Native	FORB
<i>Potentilla pensylvanica</i>	Cinquefoil	9	Native	FORB
<i>Prunus americana</i>	Wild plum	4	Native	SHRUB
<i>Prunus virginiana</i>	Choke cherry	4	Native	SHRUB
<i>Psoralea argophylla</i>	Silver-leaf scurf-pea	4	Native	FORB
<i>Psoralea esculenta</i>	Breadroot scurf-pea	9	Native	FORB

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Scientific name	Common name	C ¹	Origin	Physiognomy
<i>Ratibida columnifera</i>	Prairie coneflower	3	Native	FORB
<i>Rhus aromatica</i>	Fragrant sumac, Polecat bush	7	Native	SHRUB
<i>Rosa arkansana</i>	Prairie wild rose	3	Native	SHRUB
<i>Salsola iberica</i>	Russian thistle, Tumbleweed	*	Introduced	FORB
<i>Schedonnardus paniculatus</i>	Tumblegrass	1	Native	GRASS
<i>Selaginella densa</i>	Small clubmoss	6	Native	FERN
<i>Senecio plattensis</i>	Prairie ragwort	6	Native	FORB
<i>Shepherdia argentea</i>	Buffaloberry	5	Native	SHRUB
<i>Sisymbrium altissimum</i>	Tumbling mustard	*	Introduced	FORB
<i>Sisyrinchium campestre</i>	White-eyed grass	10	Native	FORB
<i>Solidago canadensis</i> var. <i>canadensis</i>	Canada goldenrod	1	Native	FORB
<i>Solidago missouriensis</i>	Prairie goldenrod	5	Native	FORB
<i>Solidago mollis</i>	Soft goldenrod	6	Native	FORB
<i>Solidago ptarmicoides</i>	Sneezewort aster	8	Native	FORB
<i>Solidago rigida</i>	Rigid goldenrod	4	Native	FORB
<i>Sphaeralcea coccinea</i>	Red false mallow	4	Native	FORB
<i>Spiraea alba</i>	Meadow-sweet	7	Native	SHRUB
<i>Sporobolus cryptandrus</i>	Sand dropseed	6	Native	GRASS
<i>Symphoricarpos occidentalis</i>	Western snowberry	3	Native	SHRUB
<i>Symphyotrichum ericoides</i>	White aster	2	Native	FORB
<i>Symphyotrichum falcatus</i>	N/A	4	Native	FORB
<i>Symphyotrichum laeve</i> var. <i>geyeri</i>	Smooth blue aster	5	Native	FORB
<i>Taraxacum officinale</i>	Common dandelion	*	Introduced	FORB
<i>Thalictrum dasycarpum</i>	Purple meadow rue	7	Native	FORB
<i>Thermopsis rhombifolia</i>	Prairie buck bean, Yellow pea	6	Native	FORB
<i>Thlaspi arvense</i>	Field pennycress	*	Introduced	FORB
<i>Toxicodendron rydbergii</i>	Poison ivy	3	Native	SHRUB

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Table A3. Plant species observed on 171 modified Whittaker plots on 57 study sites in the Little Missouri National Grassland, 2014 and 2015. Floristic composition was measured only once in the two field seasons, one-half of the study sites in the first year and one-half during the second year. Non-native species are not assigned a C value (continued). The species are in alphabetical order.

<i>Tradescantia bracteata</i>	Spiderwort	7	Native	FORB
<i>Tragopogon dubius</i>	Goat's beard	*	Introduced	FORB
<i>Verbena bracteata</i>	Prostrate vervain	0	Native	FORB
<i>Vicia americana</i> var. <i>americana</i>	American vetch	6	Native	FORB
<i>Viola pedatifida</i>	Prairie violet, Larkspur-violet	8	Native	FORB
<i>Yucca glauca</i>	Yucca	6	Native	SHRUB

¹ Coefficients of conservatism (C values) developed for North and South Dakota.

Table A4. Summary of average measurements of vegetation composition variables on 57 sites in the Little Missouri National Grassland in western North Dakota, 2014 and 2015.

Site	FQI	Total species	Native species	Non-native species	% Native	% Non-native
1	42.1	74	68	6	91.9	8.1
2	30.9	58	47	11	81.0	19.0
3	32.5	50	43	7	86.0	14.0
4	40.4	58	54	4	93.1	6.9
5	36.9	69	59	10	85.5	14.5
6	23.4	35	27	8	77.1	22.9
7	47.4	87	77	10	88.5	11.5
8	30.8	50	43	7	86.0	14.0
9	34.6	59	50	9	84.7	15.3
10	38.2	63	56	7	88.9	11.1
11	30.4	46	40	6	87.0	13.0
12	30.5	52	42	10	80.8	19.2
13	46.5	84	74	10	88.1	11.9
14	28.1	44	33	11	75.0	25.0
15	35.5	63	57	6	90.5	9.5
17	40.5	67	63	4	94.0	6.0
18	31.8	48	39	9	81.3	18.8
19	38.3	68	61	7	89.7	10.3
20	42.5	71	62	9	87.3	12.7
22	35.4	58	50	8	86.2	13.8
23	29.6	47	38	9	80.9	19.1
24	32.4	56	52	4	92.9	7.1
25	38.8	62	58	4	93.5	6.5
26	38.5	66	57	9	86.4	13.6
27	34.6	53	48	5	90.6	9.4
28	40.5	70	63	7	90.0	10.0
29	39.3	57	53	4	93.0	7.0
30	42.7	69	65	4	94.2	5.8
31	32.9	56	47	9	83.9	16.1
32	35.0	58	51	7	87.9	12.1
33	40.1	76	67	9	88.2	11.8
34	43.5	80	70	10	87.5	12.5
35	47.9	87	76	11	87.4	12.6
36	49.2	87	80	7	92.0	8.0
37	51.0	90	83	7	92.2	7.8
38	45.4	73	68	5	93.2	6.8
39	45.7	75	69	6	92.0	8.0
40	30.2	37	35	2	94.6	5.4
41	41.3	71	63	8	88.7	11.3

Table A4. Summary of average measurements of vegetation composition variables on 57 sites in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (continued).

Site	FQI	Total species	Native species	Non-native species	% Native	% Non-native
42	38.2	62	56	6	90.3	9.7
43	41.9	69	65	4	94.2	5.8
44	46.8	83	78	5	94.0	6.0
45	48.3	89	80	9	89.9	10.1
46	49.2	90	86	4	95.6	4.4
47	39.6	64	58	6	90.6	9.4
48	45.4	71	68	3	95.8	4.2
49	30.2	46	35	11	76.1	23.9
50	46.1	79	73	6	92.4	7.6
51	39.9	71	59	12	83.1	16.9
52	44.7	79	71	8	89.9	10.1
54	31.2	60	48	12	80.0	20.0
55	43.8	64	59	5	92.2	7.8
56	34.2	49	45	4	91.8	8.2
57	52.2	92	87	5	94.6	5.4
58	38.1	71	63	8	88.7	11.3
59	46.3	83	71	12	85.5	14.5
60	43.5	76	70	6	92.1	7.9